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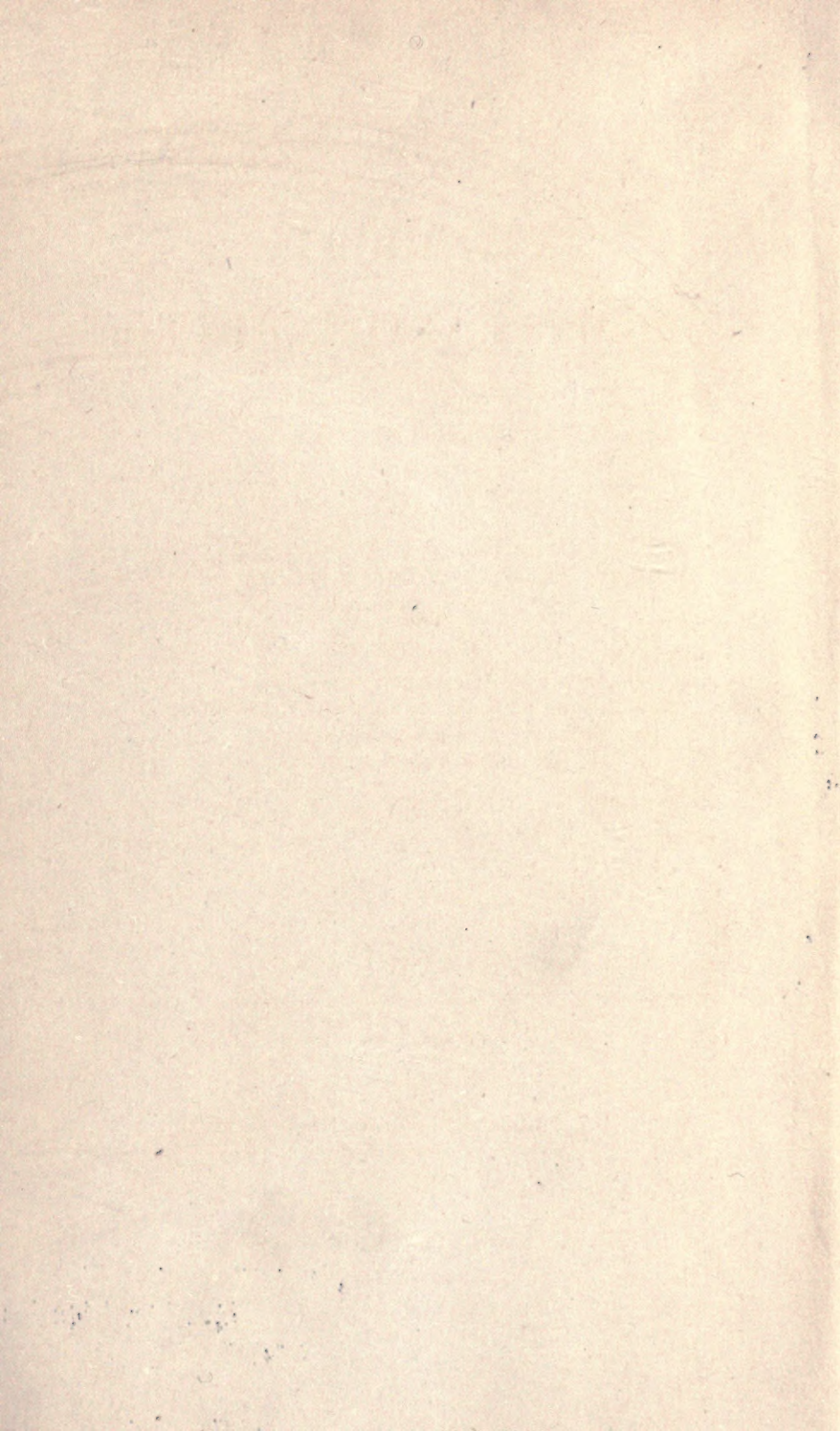


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PHARMACEUTICAL
AND
CHEMICAL
PROBLEMS AND EXERCISES

WITH
EXPLANATORY TEXT

INCLUDING
PHARMACEUTICAL AND CHEMICAL ARITHMETIC, WEIGHTS AND
MEASURES, SPECIFIC DENSITY AND SPECIFIC VOLUME X

AND
CHEMICAL NOTATION AND NOMENCLATURE, CHEMICAL EQUA-
TIONS, PROBLEMS IN OXIDATION AND REDUCTION, AND
STOICHIOMETRY. TOGETHER WITH THE ELEMENTARY
THEORETICAL CHEMISTRY NECESSARY
TO THEIR UNDERSTANDING

INTENDED AS AID TO STUDENTS, TEACHERS AND EXAMINERS

BY
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GENERAL, MEDICAL AND PHARMACEUTICAL, ETC.

FOURTH EDITION
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PREFACE
TO
THE FOURTH EDITION.

Three editions of this little book are exhausted. A fourth edition is hereby offered fully revised and containing much new matter. The lack of a suitable text book on the subject with sufficient exercises in pharmaceutical and chemical arithmetic, chemical notation and nomenclature, chemical equations and stoichiometric problems has prompted me to this effort to supply the want. Thirty-five years' experience as a teacher has convinced me that it is impossible to give students the required amount and variety of practical work of this nature without the aid of a text book, since the time and labor necessary to prepare needed examples from lesson to lesson are far greater than the teacher can bestow.

Students of pharmacy have had the arithmetic taught in the secondary schools before taking up their special technical courses, but so many of them are deficient in it that a review with further practice is often indispensable.

The problems and exercises of Parts I to VI may be undertaken without previous instruction in pharmacy or chemistry. The chemical problems and exercises may be employed either concurrently with, or after, the first year's course in chemistry.

Notation and equation writing are given a large share of attention. The eighty pages devoted to theoretical chemistry, the law of periodicity, and the classification of inorganic compounds, have been written for the express purpose of preparing the student to intelligently grasp the system of chemical notation and the method of writing equations. The manner of treatment of these subjects is in some respects new.

Those who can not understand and quickly solve such problems as are presented in this book can not be competent practical pharmacists or chemists. Consequently students should learn as early as practicable how to write molecular formulas

and how to balance chemical equations, and to that end should first learn the relations of valence and chemical polarity so clearly shown by the Periodic System. Equations in which oxidation and reduction take place are often found extremely difficult unless the student has acquired a right conception of the difference between the valence of positive elements and the valence of negative elements and is able to identify positive and negative atoms respectively. This identification may be easily effected with the aid of the Periodic System as explained on pages 177 to 185 and 311 to 322. A new form of "periodic table" is presented on page 191 which brings out clearly the lessons of the law of periodicity and the relative positions of positive and negative elements in the periodic system of their classification.

OSCAR OLDBERG.

Chicago, November, 1907.

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PHARMACEUTICAL AND CHEMICAL PROBLEMS AND EXERCISES

PART I.

REVIEW COURSE IN ELEMENTARY ARITHMETIC

CHAPTER I.

FRACTIONS.

Mathematically a **fraction** is an expression signifying any given number of equal parts of any given size into which parts any given value is divided. Thus $\frac{2}{3}$ is a fraction signifying two thirds, or two out of three equal parts of whatever unit the fraction refers to; $\frac{3}{2}$ is another fraction signifying three times one half of the unit referred to.

A fraction is an unsolved problem in division; $\frac{2}{3}$ means 2 divided by 3; $\frac{3}{2}$ means 3 divided by 2.

A **common fraction** is one expressed by a formula consisting of two **terms** separated by a horizontal or a diagonal line as shown in $\frac{2}{3}$ and $\frac{2}{3}$. In the fraction $\frac{2}{3}$ or $\frac{2}{3}$ the 2 is the **upper term** and is called the **numerator** because it states the **number** of parts; 3 is the **lower term** and the **denominator** because it **names** the parts or indicates their size or value.

$\frac{3}{10}$ is a common fraction indicating that the unit to which it refers is divided into 10 equal parts called tenths, and that 3 such parts or three tenths are designated. The numerator of $\frac{3}{10}$ is 3 and the denominator is 10, and $\frac{3}{10}$ is an unsolved problem in division, the numerator being the dividend and the denominator the divisor.

A **decimal fraction** is a fraction of which the denominator is 10 or a power of 10, and it is, therefore, easily expressed by one set of figures preceded by a period called the decimal point. That set of figures is the numerator of

the decimal fraction and the denominator is never written but is understood from the number of figures in the numerator. The common fraction $\frac{1}{10}$ converted into a decimal fraction is written 0.1 and the common fraction $\frac{1}{100}$ written in the form of a decimal fraction is 0.01, for the first figure after the decimal point stands for tenths, the second for hundredths, the third for thousandths, etc. This is rendered possible by the fact that our whole system of arithmetical notation is decimal whereby any figure in any number of more than one figure has ten times the value of the figure placed next after it and one tenth the value of the figure immediately preceding it.

The number 1234.56789—one thousand two hundred and thirty-four and fifty-six thousand seven hundred and eighty-nine hundred-thousandths—is a decimal expression. It is

1 thousand.	5 tenths.
2 hundreds.	6 hundredths.
3 tens.	7 thousandths.
4 units.	8 ten-thousandths.
	9 hundred-thousandths.

To multiply this number by 10 we simply move the decimal point one place to the right; to divide it we move the decimal point one place to the left. One hundred times 1234.56789 is 123456.789. The thousandth part of 1234.56789 is 1.23456789.

One kilogram is equal to 1000 grams; therefore 1.23456789 kilograms is 1234.56789 grams. One gram is 1000 milligrams; therefore, 1234.56789 grams must be 1234567.89 milligrams.

Any whole number may be converted into a fraction expressing the same value by simply using that number as numerator and 1 as denominator. Thus 27 is $\frac{27}{1}$ or 27 times 1. But if the number 27 be used as the denominator and 1 as the numerator the fraction is $\frac{1}{27}$ which signifies one out of 27 equal parts of 1. The fraction $\frac{27}{27}$ means twenty-seven twenty-sevenths which is equal to 1.

Any fraction of which the numerator and the denominator are identical numbers is equal to 1, or its value is the unit of which the denominator indicates the number of equal parts.

A "proper fraction" is one the denominator of which is a greater number than the numerator. An "improper fraction" is one of which the upper term is a greater number than the lower term.

A "mixed number" is a whole number with a fraction added. Thus $1\frac{1}{2}$, $3\frac{3}{4}$ and $5\frac{1}{2}$ are mixed numbers. Improper fractions may be converted into mixed numbers by dividing the numerator by the denominator and mixed numbers are converted into improper fractions by adding to the numerator of the fraction the product of the whole number multiplied by the denominator.

$\frac{3}{4}$ is a proper fraction; $\frac{3}{2}$ is a so-called improper fraction; $1\frac{1}{2}$ is a mixed number; $\frac{3}{2}$ can be converted into the corresponding mixed number $1\frac{1}{2}$, as described; the mixed number $1\frac{1}{2}$ may be converted into the corresponding improper fraction $\frac{3}{2}$.

The multiplication or division of both the numerator and the denominator of any fraction by the same multiplier does not change the value of the fraction. The value of $\frac{3}{4}$ is not changed by multiplying both of its terms by 3 for $\frac{9}{12}$ is equal to $\frac{3}{4}$. The value of $\frac{2}{4}$ is the same as that of $\frac{1}{2}$, and that of $\frac{3}{6}$ is the same as that of $\frac{1}{2}$.

The multiplication of the numerator of any fraction by any given number multiplies the value of the fraction by that number. Three times $\frac{1}{2}$ is $\frac{3}{2}$.

The multiplication of the denominator of any fraction by any given number divides the value of the fraction by that number, because it reduces the size of the equal parts into which the unit is divided. The greater the number of equal parts into which any value is divided, the smaller must be each part. Thus to multiply the lower term of $\frac{3}{7}$ by 3 is to reduce each seventh to one-third of its value; $\frac{3}{21}$ is one third of $\frac{3}{7}$.

The division of the numerator by any given number divides the value of the fraction by that number; $\frac{3}{7}$ divided by 3 is $\frac{1}{7}$.

The division of the denominator of a fraction by any given number multiplies the value of the fraction by that number, because it multiplies the value of each equal part; $\frac{3}{7}$ is three times as much as $\frac{3}{21}$ and $\frac{3}{21}$ is only one third of $\frac{3}{7}$.

The following equations further exemplify the foregoing propositions:

$$a. \frac{1}{1} = 1.$$

$$b. \frac{1 \times 3}{1 \times 3} = \frac{3}{3} = 1.$$

$$c. \frac{3 \div 3}{3 \div 3} = 1.$$

$$d. \frac{1 \times 3}{1} = 3.$$

$$e. \frac{1}{1 \times 3} = \frac{1}{3}.$$

$$f. \frac{6 \div 2}{6} = \frac{3}{6} = \frac{1}{2}.$$

$$g. \frac{6}{6 \div 2} = \frac{6}{3} = 2.$$

Fractions the numerators and denominators of which contain common divisors (or common factors, which is the same thing) may be reduced to lower terms by dividing both by those common divisors. Thus we reduce $\frac{4}{8}$ to its lowest terms or $\frac{1}{2}$ by dividing the numerator 4 and the denominator 8 by their common factor 4.

The fraction $\frac{84}{168}$ can be reduced to $\frac{1}{2}$ by the common factor 2; to $\frac{21}{42}$ by 3; to $\frac{7}{14}$ by 4; to $\frac{1}{2}$ by 6; to $\frac{1}{2}$ by 7; to $\frac{1}{2}$ by 12; to $\frac{1}{2}$ by 14; to $\frac{1}{2}$ by 21; to $\frac{1}{2}$ by 28; to $\frac{1}{2}$ by 42; and to $\frac{1}{2}$ by 84. The numbers 2, 3, 4, 6, 7, 12, 14, 21, 28, 42, and 84 are all common divisors or common factors of 84 and 168. The common **prime factors** of 84 and 168 are 3, 4 and 7, because $3 \times 4 \times 7 = 84$ and 168 is 84×2 . The **greatest common divisor** of 84 and 168 is 84.

Like fractions are fractions having identical denominators, as $\frac{1}{2}$, $\frac{2}{2}$, $\frac{3}{2}$, $\frac{5}{2}$, etc. Unlike fractions have different denominators, as $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{5}{7}$, $\frac{2}{9}$, etc.

Unlike fractions may readily be converted into like fractions of which the common or identical denominator is the direct common multiple of the different denominators of the unlike fractions. This may be clearly understood from the following facts: The product of any two numbers is their direct common multiple. Thus 6 is the direct common multiple of 2 and 3 because twice 3 is 6 and three times 2 is 6. Hence the unlike fractions $\frac{1}{2}$ and $\frac{1}{3}$ may be reduced to like fractions having the common denominator 6. The unlike fractions $\frac{1}{3}$ and $\frac{1}{4}$ can be reduced to like fractions with 20 as their com-

mon denominator because 4 times 5 is 20; the common denominator of the like fractions which equal the unlike fractions $\frac{1}{3}$ and $\frac{1}{5}$ must be 15 which is the direct common multiple (as well as the **least** common multiple) of 3 and 5. In other words, to find at once a common denominator for the like fractions sought, multiply the denominators of the unlike fractions. If the denominators of the unlike fractions are 3 and 4, then the common denominator of the corresponding like fractions may be made 12; if the unlike denominators be 8 and 9, the denominator of the like fractions may be made 72.

But the problem before us is to convert two unlike fractions into like fractions **without changing their respective values**. This requirement is met by the following rule: To convert two unlike fractions into two like fractions without changing their values, multiply both terms of each fraction by the denominator of the other fraction. That the application of this rule does not change the value of either fraction we know from the fact that the multiplication of both terms of any fraction by the same number does not change its value.

To reduce the unlike fractions $\frac{1}{4}$ and $\frac{1}{5}$ to the corresponding like fractions without changing their values we change the fourths and the fifths to twentieths by multiplying both terms of the first fraction by 5 and both terms of the second by 4; this procedure will give us $\frac{5}{20}$ as the equivalent of $\frac{1}{4}$ and $\frac{4}{20}$ as the equivalent of $\frac{1}{5}$.

The **least common multiple** of any two or more numbers is the smallest number which can be divided by each of them, or, in other words, the smallest number of which each is a factor.

When two unlike fractions are converted into like fractions the problem is simplified by making the common denominator of the like fractions not only a "common multiple" of the denominators of the unlike fractions but the "**least** common multiple" of them.

The least common multiple of 8 and 10 is not 80 but 40. Hence the unlike fractions $\frac{1}{8}$ and $\frac{1}{10}$ may be converted into the like fractions $\frac{5}{40}$ and $\frac{4}{40}$ instead of $\frac{10}{80}$ and $\frac{8}{80}$.

The least common multiple of 2, 3, 4, 5 and 6 is 60. Hence the unlike fractions $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$ and $\frac{1}{6}$ may be converted into the like fractions $\frac{30}{60}$, $\frac{20}{60}$, $\frac{15}{60}$, $\frac{12}{60}$ and $\frac{10}{60}$.

A common fraction may be converted into a decimal fraction by dividing the numerator by the divisor and giving the quotient in decimal form in the usual way.

A decimal fraction may be converted into a common fraction by drawing a line under the numerator and writing below that line the denominator which is the figure 1 followed by as many zeros as there are figures in the numerator after the decimal point.

ADDITION OF FRACTIONS.

When like fractions are to be added together we find the sum of their numerators make the sum the numerator of the answer and leave the common denominator of the fractions unchanged. Thus $\frac{1}{9}$, $\frac{2}{9}$, $\frac{3}{9}$ and $\frac{4}{9}$ make $\frac{10}{9}$ or $1\frac{1}{9}$.

When unlike fractions are to be added together they must first be converted into like fractions. Thus $\frac{3}{4}$ and $\frac{4}{5}$ are converted into $\frac{15}{20}$ and $\frac{16}{20}$ and their sum is $\frac{31}{20}$ or $1\frac{11}{20}$. The sum of $\frac{2}{5}$ and $\frac{1}{7}$ is $\frac{19}{35}$ for $\frac{2}{5}$ is $\frac{14}{35}$ and $\frac{1}{7}$ is $\frac{5}{35}$. The sum of $\frac{1}{2} + \frac{2}{3} + \frac{3}{4} + \frac{4}{5} + \frac{5}{6}$ is the sum of $\frac{30}{60} + \frac{40}{60} + \frac{45}{60} + \frac{48}{60} + \frac{50}{60} = \frac{213}{60}$ or $\frac{71}{20}$ or $3\frac{11}{20}$.

SUBTRACTION OF ONE FRACTION FROM ANOTHER.

When one fraction is to be subtracted from another the numerator of the minuend is subtracted from the numerator of the subtrahend if the fractions have like denominators: the remainder is the numerator of the answer and the denominator is left unchanged. Thus $\frac{1}{35} - \frac{5}{35} = \frac{9}{35}$.

But when one fraction is to be deducted from another and unlike fraction both fractions must first be converted into like fractions. Thus in subtracting $\frac{1}{7}$ from $\frac{2}{5}$ we first convert $\frac{2}{5}$ to $\frac{14}{35}$ and $\frac{1}{7}$ to $\frac{5}{35}$.

MULTIPLICATION OF FRACTIONS.

When a fraction is to be multiplied by a whole number, the numerator is multiplied by that number and the product is the numerator of the answer while the denominator is the same as before. Thus $\frac{3}{7} \times 4$ is $\frac{12}{7}$ or $1\frac{5}{7}$. This will be clearly understood from the fact that the denominator simply

signifies the kind or size of the unit to be multiplied or is in fact merely the name or denomination of that unit. Four times 3 pounds is 12 pounds, and 4 times 3 sevenths is 12 sevenths.

If the denominator of the fraction is divisible by the whole number which constitutes the multiplier, then the product can be found by division instead of multiplication; the quotient obtained by dividing the denominator of the fraction by the whole number is then the new denominator, or the denominator of the answer, while the numerator is left unchanged. Thus $\frac{3}{8} \times 4$ is $\frac{3}{2}$, because by dividing the denominator 8 by 4 we have changed the eighths into halves or made the units (the parts into which the integral unit referred to by the fraction is divided) four times as great. Four times $\frac{1}{8}$ pound is $\frac{4}{8}$ pound, and it is also $\frac{1}{2}$ pound; and four times $\frac{3}{8}$ pound is $\frac{12}{8}$ pound or $\frac{3}{2}$ pound or $1\frac{1}{2}$ pounds.

To multiply any number by a fraction is to multiply that number by the numerator of that fraction and to divide the product by its denominator.

Thus, to multiply 12 by $\frac{3}{4}$ is to multiply 12 by 3 and to divide the product, 36, by 4.

To multiply $1\frac{1}{2}$ by $\frac{2}{3}$ is to multiply $1\frac{1}{2}$ or $\frac{3}{2}$ by 2 and then divide by 3.

To multiply 32 by $\frac{1}{2}$ is to multiply 32 by 1 and divide by 2.

To multiply 32 by $1\frac{1}{2}$, or 32 by $\frac{3}{2}$ is to multiply 32 by 3 and divide the product by 2.

To multiply $\frac{1}{2}$ by $\frac{2}{3}$ is to multiply $\frac{1}{2}$ by 2 and divide the product by 3.

To multiply $\frac{1}{2}$ by $\frac{3}{4}$ is to multiply $\frac{1}{2}$ by 3 and divide the product by 4; that is $\frac{1}{2} \times \frac{3}{4} = \frac{1}{2} \times 3 \div 4$ which gives us $\frac{3}{2} \div 4$, or $\frac{3}{8}$. That this must be correct may be seen from the fact that to multiply $\frac{1}{2}$ by 3 is to multiply the nominator of $\frac{1}{2}$ by 3, which gives us $\frac{3}{2}$, and to divide $\frac{3}{2}$ by 4 is to multiply the denominator of $\frac{3}{2}$ by 4 which gives us $\frac{3}{8}$.

The student is reminded once more that all fractions are problems in division of which the numerators are the dividends and the denominators the divisors, and that the multiplication of the numerator of a fraction by any number is a multiplication of the value of the fraction as a whole, while

the multiplication of the denominator by any number is a division of that value.

$$\frac{3}{7} \times 4 = \frac{12}{7}.$$

$$\frac{3}{7} \div 4 = \frac{3}{28}.$$

$$\frac{3}{7} \div 9 = \frac{3}{63} \text{ or } \frac{1}{21}.$$

$$\frac{3}{7} \times \frac{4}{9} = \frac{3 \times 4}{7 \times 9} = \frac{12}{63} = \frac{4}{21}.$$

When a mixed number is to be multiplied by a whole number, as $1\frac{1}{2}$ by 32, we may first multiply the integer of the mixed number by the multiplier and then add the product of the fraction and the multiplier, thus: $1\frac{1}{2} \times 32$ is $32 + \frac{32}{2}$, or $32+16=48$. Or we may first convert the mixed number into an improper fraction and then multiply its numerator by the multiplier, thus: $1\frac{1}{2}$ is $\frac{3}{2}$, and $\frac{3}{2} \times 32$ is $\frac{96}{2}$ or 48. In this example we find that the denominator of the fraction $\frac{3}{2}$ and the multiplier 32 have the common divisor 2; we may, therefore, reduce the problem to simpler terms by cancellation as

follows: $\frac{3}{2} \times 32$ is $\frac{3 \times \overset{16}{\cancel{32}}}{\cancel{2}}$ and 3×16 is 48. (See Cancellation, page 9).

To multiply any number successively by two or more factors is the same as to multiply that number by the product of those several factors. Thus, to multiply 3 by 4 and by 5 is the same as to multiply 3 by 20; $3 \times 4 \times 5$ is equal to 3×20 , and to 12×5 , and to 15×4 .

To divide any number successively by two or more divisors is the same as to divide that number by the product of those several divisors. Thus, to divide 60 first by 3 and then the quotient by 4 is the same as to divide 60 by 3×4 ;

$\frac{60}{3} \div 4$ is equal to $\frac{60}{3 \times 4}$ and to $\frac{60}{4} \div 3$.

From the foregoing facts it follows that the product of any number of fractions is represented by a fraction the numerator of which is the product of all the numerators of the several factors, and the denominator the product of their several

denominators. Thus the product of $\frac{1}{2} \times \frac{2}{3} \times \frac{3}{4} \times \frac{4}{5} \times \frac{5}{6}$ is $1 \times 2 \times 3 \times 4 \times 5$
 $2 \times 3 \times 4 \times 5 \times 6$. All the numbers above the horizontal line are

dividends; all the numbers below it are divisors. The whole statement is a problem in division. All the dividends are to be multiplied together; all the divisors are also to be multiplied. Instead of repeating the signs of multiplication both above and below the line it is convenient to place them on the

line, thus—

$$\frac{1 \times 2 \times 3 \times 4 \times 5}{2 \times 3 \times 4 \times 5 \times 6}$$

The work required to solve problems involving the multiplication of fractions, and any other problems dealing with both multiplication and division (thus including problems in proportion) can be simplified by cancellation in all cases wherein factors and products, dividends and divisors, or numerators and denominators, contain common factors or divisors.

Cancellation in mathematics means the striking out or elimination of common factors or terms of both dividends and divisors.

In the problem $\frac{1}{2} \times \frac{2}{3}$ we see at once that the common factor 2 is contained as a dividend in $\frac{2}{3}$ and as a divisor in

$\frac{1}{2}$. We may, therefore, cancel or eliminate it— $\frac{1}{\cancel{2}} \times \frac{\cancel{2}}{3} = \frac{1}{3}$.

In the multiplication of $\frac{3}{4}$ by $\frac{10}{12}$ and by $\frac{24}{35}$ we can proceed as follows:

$$\frac{3 \times 10 \times 24}{4 \times 12 \times 35}$$

As 10 and 35 are both divisible by 5, and 12 and 24 are divisible by 12, we cancel these common factors:

$$\frac{3 \times \overset{2}{\cancel{10}} \times \overset{2}{\cancel{24}}}{4 \times \underset{7}{\cancel{12}} \times \underset{7}{\cancel{35}}}$$

We can carry the cancellation further because 2 is a common factor of 2 and 4, thus:

$$\frac{3 \times \cancel{2} \times 2}{\cancel{4} \times 7}$$

Our answer is accordingly $\frac{3}{7}$.

In solving the example: $\frac{1}{2} \times \frac{2}{3} \times \frac{3}{4} \times \frac{4}{5} \times \frac{5}{6}$ we cancel as follows:

$$\frac{1}{\cancel{2}} \times \frac{\cancel{2}}{\cancel{3}} \times \frac{\cancel{3}}{\cancel{4}} \times \frac{\cancel{4}}{\cancel{5}} \times \frac{\cancel{5}}{6}$$

and thus obtain the result $\frac{1}{6}$ at once.

The student will understand that the product of any factors is the same without regard to the order in which those factors are successively used. The problem 1×2 is the same as 2×1 , and $1 \times 2 \times 3$ is the same as $1 \times 3 \times 2$, or $3 \times 2 \times 1$, or $2 \times 1 \times 3$, or $2 \times 3 \times 1$, or $3 \times 1 \times 2$. Hence $\frac{1}{2} \times \frac{2}{3} \times \frac{3}{4} \times \frac{4}{5} \times \frac{5}{6}$ must be the same as $\frac{1}{6} \times \frac{2}{3} \times \frac{3}{4} \times \frac{4}{5} \times \frac{5}{6}$ and as multiplication or division of both terms of any fraction by the same numbers or by the same successive numbers can not change its value, it follows that the value of $\frac{1}{6}$ can not be changed by multiplying its terms by 2, 3, 4 and 5 successively; hence we strike these numbers out.

In all problems involving multiplication or division or both, it will be found useful to employ the reciprocals of the factors or divisors whenever their use simplifies the work. Division by any number is equivalent to multiplication by the reciprocal of the same number, and multiplication by any number is equivalent to division by the reciprocal of the same number. The student should compare these statements with the operations involved in cancellation and in the multiplication and division of fractions.

DIVISION OF AND BY FRACTIONS.

To divide one number by any other number is to find how many times the divisor is contained in the dividend.

It makes no difference whether one or both numbers are whole numbers, or fractions, or mixed numbers.

To divide a whole number by a fraction is to find how many times that fraction is contained in the whole number. Thus, to divide 2 by $\frac{1}{3}$, or to find how many times $\frac{1}{3}$ is contained in 2, we invert the terms of the divisor and then multiply the inverted fraction by the whole number: $2 \div \frac{1}{3}$ is equal to $2 \times \frac{3}{1}$; the answer is $\frac{6}{1}$ or 2 $\frac{2}{3}$.

To find how many times a given whole number is contained in any fraction, multiply the denominator of the fraction by the whole number. Thus to find how many times 2 is contained in $\frac{1}{2}$ we multiply the denominator of $\frac{1}{2}$ by 2 which gives us $\frac{1}{1}$ as the answer.

To divide one fraction by another invert the divisor and then proceed as in the multiplication of fractions by each other. To divide $\frac{3}{7}$ by $\frac{4}{5}$ is to find out how many times $\frac{4}{5}$ is contained in $\frac{3}{7}$. We invert the terms of the divisor $\frac{4}{5}$ and then multiply $\frac{3}{7}$ by $\frac{5}{4}$. To divide by $\frac{4}{5}$ is to multiply by $\frac{5}{4}$. The answer is $\frac{3 \times 5}{7 \times 4} = \frac{15}{28}$. That this must be so may be seen from the fact that the multiplication of one of the terms of any fraction by any given number is equivalent to the division of the other term of that fraction by the same number. In other words, $2 \div \frac{1}{2}$ is $\frac{2 \times 2}{1}$; $\frac{1}{2} \div 2$ is $\frac{1}{2 \times 2}$; $\frac{3}{7} \div \frac{4}{5}$ is $\frac{3}{7} \times \frac{5}{4}$ or $\frac{3 \times 5}{7 \times 4}$; $\frac{3}{4} \div \frac{1}{2}$ is $\frac{3}{4} \times \frac{2}{1}$ or $\frac{3 \times 2}{4}$. That $\frac{1}{12}$ is contained in $\frac{3}{4}$ nine times is evident from the fact that $\frac{3}{4}$ is equal to $\frac{3 \times 3}{4 \times 3}$, $\frac{1}{12}$ is equal to $\frac{1}{4 \times 3}$ and $\frac{1}{4 \times 3}$ is contained in $\frac{3 \times 3}{4 \times 3}$ 9 times.

From the fact that division by any number is equivalent to multiplication by the reciprocal of that number, we can reduce the division of any number by a fraction to the following simple rule:

To find the quotient obtained by dividing any number by any given fraction, multiply that number by the reciprocal of that fraction. As the reciprocal of $\frac{2}{3}$ is $\frac{3}{2}$ it follows that $\frac{3}{4} \div \frac{2}{3}$ is $\frac{3}{4} \times \frac{3}{2}$.

This rule, and the fact that the reciprocal of any fraction is found by inverting its terms, explain why division by a fraction is performed by inverting the divisor and then proceeding as in multiplication.

CHAPTER II.

RECIPROCALS OF NUMBERS AND THEIR USES.

The **reciprocal** of any number is the quotient obtained by dividing 1 by that number.

Hence it follows that the product found by multiplying any number by its reciprocal is 1.

Designating the number by **a** and its reciprocal by **b** we shall have the following equations:

$$a \times b = 1; \frac{1}{a} = b; \frac{1}{b} = a$$

It follows, further, that whenever any number is expressed in the form of a common fraction the reciprocal is found by inverting that fraction. Thus the reciprocal of $\frac{1}{10}$ is 10 ; that of $\frac{10}{1}$ is $\frac{1}{10}$; the reciprocal of $\frac{4}{5}$ is $\frac{5}{4}$; etc.

The reciprocal of 1 is 1; the reciprocal of any number greater than 1 must be less than 1, and that of any fraction of 1 must be greater than 1.

Division by any number gives the same result as multiplication by the reciprocal of the same number.

Multiplication by any number gives the same result as division by the reciprocal of the same number.

As multiplication is generally an easier process than division it follows that arithmetical computations involving division may frequently be simplified. Instead of dividing by a given number, multiply by the reciprocal of that number. The quotient obtained by division is identical with the product obtained by multiplying the dividend by the reciprocal of the divisor.

Multiples of the reciprocals of divisors may be conveniently employed to shorten calculations in cases where many different numbers are to be divided by the same divisor. Such calculations occur frequently in converting units of weights

and measures of one system into units of another system, and in many chemical problems involving the use of atomic weights.

Whenever 1 or 10 or any power of 10 is to be divided by any given number the reciprocal of that number may be conveniently used as a multiplier to find the answer. Thus when 10 is to be divided by 3 [$\frac{10}{3}$] the answer is at once found by multiplying the reciprocal of 3 [$\frac{1}{3}$] by 10; stated in the form of decimal fractions we find that as the reciprocal of 3 is 0.3333', the quotient sought must be $0.3333' \times 10$ or 3.333'.

The reciprocal of the number expressing the specific density of any solid or liquid is the numerical expression of the specific volume of that solid or liquid. Thus if the specific density be 0.666' the specific volume must be 1.500 for 1.500 is the reciprocal of 0.666'.

If the specific volume of a liquid be 0.800, then its specific density must be 1.250, for $0.800 \times 1.250 = 1$.

As one commercial (or avoirdupois) pound is equal to 0.453594 kilogram one kilogram is equal to 2.2046 pounds, because 2.2046 is the reciprocal of 0.453594.

As one meter is equal to 39.37 inches it follows that 1 inch is 25.4 millimeters, for the reciprocal of 39.37 is 0.0254.

To find the percentage (proportion per 100) which any number, **a**, bears to any other number, **b**, multiply the reciprocal of the latter number (**b**) by 100 times the first number (**a**). Thus, to find what per cent 3 is of 20 we may multiply the reciprocal of 20, which is $\frac{1}{20}$ or 0.05 by 300 (one hundred times 3); the answer is that 3 is 15 per cent of 20. To find what per cent 20 is of 3 we multiply the reciprocal of 3, which is 0.333', by 100 times 20; the answer is 666.67.

Twenty pounds of a solution containing 3 pounds of salt may accordingly be found by this method to be of 15 per cent strength, and 666.67 pounds of solution of that strength can be made out of 100 pounds of the salt.

To find the per cent. of any element in any compound: **Multiply one hundred times the atomic weight of that element by the number of atoms contained in one molecule and by the reciprocal of the molecular weight of the compound.**

The molecular weight of any compound multiplied by the

per cent, it contains of any element gives the same product as obtained by multiplying the atomic weight of that element by one hundred times the number of atoms of it which one molecule of the compound contains.

In very many instances the reciprocals of the molecular weights of common and important compounds will be found to be such as to render multiplication by them far less laborious than division by the molecular weights themselves.

Table of Reciprocals.

As this table contains the reciprocals of numbers from 1 to 2,000 carried out to nine decimals the specific volume of any liquid, the specific gravity of which is known, can be readily found from it. For example, the specific gravity being 0.720 the corresponding specific volume is found to be 1.389, for the reciprocal of 720 is 0.00138889; if the specific gravity is 1.250 the specific volume must be 0.800, for the reciprocal of 1,250 is 0.000800.

The reciprocals of decimal fractions or decimal mixed numbers may be found with the aid of this table without difficulty, as the reciprocal of the thousandth of any whole number in the table must be one thousand times the reciprocal of that whole number. Thus, we find the reciprocal of 0.130 must be 7.69231, because it is one thousand times 0.00769231, which is the reciprocal of 130; and the reciprocal of 1.300 is 0.769231. We simply move the decimal point of the reciprocal of the whole number as many places to the right as we place the decimal point in the whole number to the left.

RECIPROCAL OF NUMBERS.

No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.
1	1.	46	.02173913	91	.01098901	136	.00735294
2	.50000000	7	.02127660	2	.01086956	7	.00729927
3	.33333333	8	.02083333	3	.01075269	8	.00724638
4	.25000000	9	.02040816	4	.01063830	9	.00719424
5	.20000000	50	.02000000	5	.01052632	140	.00714286
6	.16666667	1	.01960784	6	.01041667	1	.00709220
7	.14285714	2	.01923077	7	.01030928	2	.00704225
8	.12500000	3	.01886792	8	.01020408	3	.00699301
9	.11111111	4	.01851852	9	.01010101	4	.00694444
10	.10000000	5	.01818182	100	.01000000	5	.00689655
11	.09090909	6	.01785714	1	.00990099	6	.00684931
12	.08333333	7	.01754386	2	.00980392	7	.00680272
13	.07692308	8	.01724138	3	.00970874	8	.00675676
14	.07142857	9	.01694915	4	.00961538	9	.00671141
15	.06666667	60	.01666667	5	.00952381	150	.00666667
16	.06250000	1	.01639344	6	.00943396	1	.00662252
17	.05882353	2	.01612903	7	.00934579	2	.00657895
18	.05555556	3	.01587302	8	.00925926	3	.00653595
19	.05263158	4	.01562500	9	.00917431	4	.00649351
20	.05000000	5	.01538461	110	.00909091	5	.00645161
1	.04761905	6	.01515151	11	.00900901	6	.00641026
2	.04545455	7	.01492537	12	.00892857	7	.00636943
3	.04347826	8	.01470588	13	.00884956	8	.00632911
4	.04166667	9	.01449275	14	.00877193	9	.00628931
5	.04000000	70	.01428571	15	.00869565	160	.00625000
6	.03846154	1	.01408451	16	.00862069	1	.00621118
7	.03703704	2	.01388889	17	.00854701	2	.00617284
8	.03571429	3	.01369863	18	.00847458	3	.00613497
9	.03448276	4	.01351351	19	.00840336	4	.00609756
30	.03333333	5	.01333333	120	.00833333	5	.00606061
1	.03225806	6	.01315789	1	.00826446	6	.00602410
2	.03125000	7	.01298701	2	.00819672	7	.00598802
3	.03030303	8	.01282051	3	.00813008	8	.00595238
4	.02941176	9	.01265823	4	.00806452	9	.00591716
5	.02857143	80	.01250000	5	.00800000	170	.00588235
6	.02777778	1	.01234568	6	.00793651	1	.00584795
7	.02702703	2	.01219512	7	.00787402	2	.00581395
8	.02631579	3	.01204819	8	.00781250	3	.00578035
9	.02564103	4	.01190476	9	.00775194	4	.00574713
40	.02500000	5	.01176471	130	.00769231	5	.00571429
1	.02439024	6	.01162791	1	.00763359	6	.00568182
2	.02380952	7	.01149425	2	.00757576	7	.00564972
3	.02325581	8	.01136364	3	.00751880	8	.00561798
4	.02272727	9	.01123595	4	.00746269	9	.00558659
5	.02222222	90	.01111111	5	.00740741	180	.00555556

No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.
181	.00552486	226	.00442478	271	.00369004	316	.00316456
2	.00549451	7	.00440529	2	.00367647	17	.00315457
3	.00546448	8	.00438596	3	.00366300	18	.00314465
4	.00543478	9	.00436681	4	.00364963	19	.00313480
5	.00540540	230	.00434783	5	.00363636	320	.00312500
6	.00537634	1	.00432900	6	.00362319	1	.00311526
7	.00534759	2	.00431034	7	.00361011	2	.00310559
8	.00531914	3	.00429184	8	.00359712	3	.00309597
9	.00529100	4	.00427350	9	.00358423	4	.00308642
190	.00526316	5	.00425532	280	.00357143	5	.00307692
1	.00523560	6	.00423729	1	.00355872	6	.00306748
2	.00520833	7	.00421941	2	.00354610	7	.00305810
3	.00518135	8	.00420168	3	.00353357	8	.00304878
4	.00515464	9	.00418410	4	.00352113	9	.00303951
5	.00512820	240	.00416667	5	.00350877	330	.00303030
6	.00510204	1	.00414938	6	.00349650	1	.00302115
7	.00507614	2	.00413223	7	.00348432	2	.00301205
8	.00505051	3	.00411523	8	.00347222	3	.00300300
9	.00502513	4	.00409836	9	.00346021	4	.00299401
200	.00500000	5	.00408163	290	.00344828	5	.00298507
1	.00497512	6	.00406504	1	.00343643	6	.00297619
2	.00495049	7	.00404858	2	.00342466	7	.00296736
3	.00492611	8	.00403226	3	.00341297	8	.00295858
4	.00490196	9	.00401606	4	.00340136	9	.00294985
5	.00487805	250	.00400000	5	.00338983	340	.00294118
6	.00485437	1	.00398406	6	.00337838	1	.00293255
7	.00483092	2	.00396825	7	.00336700	2	.00292398
8	.00480769	3	.00395257	8	.00335570	3	.00291545
9	.00478469	4	.00393701	9	.00334448	4	.00290698
210	.00476190	5	.00392157	300	.00333333	5	.00289855
11	.00473934	6	.00390625	1	.00332226	6	.00289017
12	.00471698	7	.00389105	2	.00331126	7	.00288184
13	.00469484	8	.00387597	3	.00330033	8	.00287356
14	.00467290	9	.00386100	4	.00328947	9	.00286533
15	.00465116	260	.00384615	5	.00327869	350	.00285714
16	.00462963	1	.00383142	6	.00326797	1	.00284900
17	.00460829	2	.00381679	7	.00325733	2	.00284091
18	.00458716	3	.00380228	8	.00324675	3	.00283286
19	.00456621	4	.00378788	9	.00323625	4	.00282486
220	.00454545	5	.00377358	310	.00322581	5	.00281690
1	.00452489	6	.00375940	11	.00321543	6	.00280899
2	.00450450	7	.00374532	12	.00320513	7	.00280112
3	.00448430	8	.00373134	13	.00319489	8	.00279330
4	.00446429	9	.00371747	14	.00318471	9	.00278551
5	.00444444	270	.00370370	15	.00317460	360	.00277778

No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.
361	.00277008	406	.00246305	451	.00221729	496	.00201613
2	.00276243	7	.00245700	2	.00221239	7	.00201207
3	.00275482	8	.00245098	3	.00220751	8	.00200803
4	.00274725	9	.00244499	4	.00220264	9	.00200401
5	.00273973	410	.00243902	5	.00219780	500	.00200000
6	.00273224	11	.00243309	6	.00219298	1	.00199601
7	.00272480	12	.00242718	7	.00218818	2	.00199203
8	.00271739	13	.00242131	8	.00218341	3	.00198807
9	.00271003	14	.00241546	9	.00217865	4	.00198413
370	.00270270	15	.00240964	460	.00217391	5	.00198020
1	.00269542	16	.00240385	1	.00216920	6	.00197628
2	.00268817	17	.00239808	2	.00216450	7	.00197239
3	.00268096	18	.00239234	3	.00215983	8	.00196850
4	.00267380	19	.00238663	4	.00215517	9	.00196464
5	.00266667	420	.00238095	5	.00215054	510	.00196078
6	.00265957	1	.00237530	6	.00214592	11	.00195695
7	.00265252	2	.00236967	7	.00214133	12	.00195312
8	.00264550	3	.00236407	8	.00213675	13	.00194932
9	.00263852	4	.00235849	9	.00213220	14	.00194552
380	.00263158	5	.00235294	470	.00212766	15	.00194175
1	.00262467	6	.00234742	1	.00212314	16	.00193798
2	.00261780	7	.00234192	2	.00211864	17	.00193424
3	.00261097	8	.00233645	3	.00211416	18	.00193050
4	.00260417	9	.00233100	4	.00210970	19	.00192678
5	.00259740	430	.00232558	5	.00210526	520	.00192308
6	.00259067	1	.00232019	6	.00210084	1	.00191939
7	.00258398	2	.00231481	7	.00209644	2	.00191571
8	.00257732	3	.00230947	8	.00209205	3	.00191205
9	.00257069	4	.00230415	9	.00208768	4	.00190840
390	.00256410	5	.00229885	480	.00208333	5	.00190476
1	.00255754	6	.00229358	1	.00207900	6	.00190114
2	.00255102	7	.00228833	2	.00207469	7	.00189753
3	.00254453	8	.00228310	3	.00207039	8	.00189394
4	.00253807	9	.00227790	4	.00206612	9	.00189036
5	.00253165	440	.00227273	5	.00206186	530	.00188679
6	.00252525	1	.00226757	6	.00205761	1	.00188324
7	.00251889	2	.00226244	7	.00205339	2	.00187970
8	.00251256	3	.00225734	8	.00204918	3	.00187617
9	.00250627	4	.00225225	9	.00204499	4	.00187266
400	.00250000	5	.00224719	490	.00204082	5	.00186916
1	.00249377	6	.00224215	1	.00203666	6	.00186567
2	.00248756	7	.00223714	2	.00203252	7	.00186220
3	.00248139	8	.00223214	3	.00202840	8	.00185874
4	.00247525	9	.00222717	4	.00202429	9	.00185528
5	.00246914	450	.00222222	5	.00202020	540	.00185185

No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.
541	.00184843	586	.00170648	631	.00158479	676	.00147929
2	.00184502	7	.00170358	2	.00158228	7	.00147710
3	.00184162	8	.00170068	3	.00157978	8	.00147493
4	.00183823	9	.00169779	4	.00157729	9	.00147275
5	.00183486	590	.00169491	5	.00157480	680	.00147059
6	.00183150	1	.00169205	6	.00157233	1	.00146843
7	.00182815	2	.00168919	7	.00156986	2	.00146628
8	.00182482	3	.00168634	8	.00156740	3	.00146413
9	.00182149	4	.00168350	9	.00156494	4	.00146199
550	.00181818	5	.00168067	640	.00156250	5	.00145985
1	.00181488	6	.00167785	1	.00156006	6	.00145773
2	.00181159	7	.00167504	2	.00155763	7	.00145560
3	.00180832	8	.00167224	3	.00155521	8	.00145349
4	.00180505	9	.00166945	4	.00155279	9	.00145137
5	.00180180	600	.00166667	5	.00155039	690	.00144927
6	.00179856	1	.00166389	6	.00154799	1	.00144718
7	.00179533	2	.00166113	7	.00154559	2	.00144509
8	.00179211	3	.00165837	8	.00154321	3	.00144300
9	.00178891	4	.00165563	9	.00154083	4	.00144092
560	.00178571	5	.00165289	650	.00153846	5	.00143885
1	.00178253	6	.00165016	1	.00153610	6	.00143678
2	.00177936	7	.00164745	2	.00153374	7	.00143472
3	.00177620	8	.00164474	3	.00153140	8	.00143266
4	.00177305	9	.00164204	4	.00152905	9	.00143061
5	.00176991	610	.00163934	5	.00152672	700	.00142857
6	.00176678	11	.00163666	6	.00152439	1	.00142653
7	.00176367	12	.00163399	7	.00152207	2	.00142450
8	.00176056	13	.00163132	8	.00151975	3	.00142247
9	.00175747	14	.00162866	9	.00151745	4	.00142045
570	.00175439	15	.00162602	660	.00151515	5	.00141844
1	.00175131	16	.00162338	1	.00151286	6	.00141643
2	.00174825	17	.00162075	2	.00151057	7	.00141443
3	.00174520	18	.00161812	3	.00150830	8	.00141243
4	.00174216	19	.00161551	4	.00150602	9	.00141044
5	.00173913	620	.00161290	5	.00150376	710	.00140845
6	.00173611	1	.00161031	6	.00150150	11	.00140647
7	.00173310	2	.00160772	7	.00149925	12	.00140449
8	.00173010	3	.00160514	8	.00149701	13	.00140252
9	.00172712	4	.00160256	9	.00149477	14	.00140056
580	.00172414	5	.00160000	670	.00149254	15	.00139860
1	.00172117	6	.00159744	1	.00149031	16	.00139665
2	.00171821	7	.00159490	2	.00148809	17	.00139470
3	.00171527	8	.00159236	3	.00148588	18	.00139276
4	.00171233	9	.00158982	4	.00148368	19	.00139082
5	.00170940	630	.00158730	5	.00148148	720	.00138889

No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal	No.	Reciprocal.
721	.00138696	766	.00130548	811	.00123305	856	.00116822
2	.00138504	7	.00130378	12	.00123153	7	.00116686
3	.00138313	8	.00130208	13	.00123001	8	.00116550
4	.00138121	9	.00130039	14	.00122850	9	.00116414
5	.00137931	770	.00129870	15	.00122699	860	.00116279
6	.00137741	1	.00129702	16	.00122549	1	.00116144
7	.00137552	2	.00129534	17	.00122399	2	.00116009
8	.00137363	3	.00129366	18	.00122249	3	.00115875
9	.00137174	4	.00129199	19	.00122100	4	.00115741
730	.00136986	5	.00129032	820	.00121951	5	.00115607
1	.00136799	6	.00128866	1	.00121803	6	.00115473
2	.00136612	7	.00128700	2	.00121654	7	.00115340
3	.00136426	8	.00128535	3	.00121507	8	.00115207
4	.00136240	9	.00128370	4	.00121359	9	.00115075
5	.00136054	780	.00128205	5	.00121212	870	.00114942
6	.00135870	1	.00128041	6	.00121065	1	.00114811
7	.00135685	2	.00127877	7	.00120919	2	.00114679
8	.00135501	3	.00127714	8	.00120773	3	.00114547
9	.00135318	4	.00127551	9	.00120627	4	.00114416
740	.00135135	5	.00127388	830	.00120482	5	.00114286
1	.00134953	6	.00127226	1	.00120337	6	.00114155
2	.00134771	7	.00127065	2	.00120192	7	.00114025
3	.00134589	8	.00126904	3	.00120048	8	.00113895
4	.00134409	9	.00126743	4	.00119904	9	.00113766
5	.00134228	790	.00126582	5	.00119760	880	.00113636
6	.00134048	1	.00126422	6	.00119617	1	.00113507
7	.00133869	2	.00126263	7	.00119474	2	.00113379
8	.00133690	3	.00126103	8	.00119332	3	.00113250
9	.00133511	4	.00125945	9	.00119189	4	.00113122
750	.00133333	5	.00125786	840	.00119048	5	.00112994
1	.00133156	6	.00125628	1	.00118906	6	.00112867
2	.00132979	7	.00125470	2	.00118765	7	.00112740
3	.00132802	8	.00125313	3	.00118624	8	.00112613
4	.00132626	9	.00125156	4	.00118483	9	.00112486
5	.00132450	800	.00125000	5	.00118343	890	.00112360
6	.00132275	1	.00124844	6	.00118203	1	.00112233
7	.00132100	2	.00124688	7	.00118064	2	.00112108
8	.00131926	3	.00124533	8	.00117924	3	.00111982
9	.00131752	4	.00124378	9	.00117786	4	.00111857
760	.00131579	5	.00124224	850	.00117647	5	.00111732
1	.00131406	6	.00124069	1	.00117509	6	.00111607
2	.00131234	7	.00123916	2	.00117371	7	.00111483
3	.00131062	8	.00123762	3	.00117233	8	.00111359
4	.00130890	9	.00123609	4	.00117096	9	.00111235
5	.00130719	810	.00123457	5	.00116959	900	.00111111

No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.
901	.00110988	946	.00105708	991	.00100908	1036	.000965251
2	.00110865	7	.00105597	2	.00100806	7	.000964320
3	.00110742	8	.00105485	3	.00100705	8	.000963391
4	.00110619	9	.00105374	4	.00100604	9	.000962464
5	.00110497	950	.00105263	5	.00100502	1040	.000961538
6	.00110375	1	.00105152	6	.00100402	1	.000960615
7	.00110254	2	.00105042	7	.00100301	2	.000959693
8	.00110132	3	.00104932	8	.00100200	3	.000958774
9	.00110011	4	.00104822	9	.00100100	4	.000957854
910	.00109890	5	.00104712	1000	.00100000	5	.000956938
11	.00109769	6	.00104602	1	.000999001	6	.000956023
12	.00109649	7	.00104493	2	.000998004	7	.000955110
13	.00109529	8	.00104384	3	.000997009	8	.000954198
14	.00109409	9	.00104275	4	.000996016	9	.000953289
15	.00109290	960	.00104167	5	.000995025	1050	.000952381
16	.00109170	1	.00104058	6	.000994036	1	.000951475
17	.00109051	2	.00103950	7	.000993049	2	.000950570
18	.00108932	3	.00103842	8	.000992063	3	.000949668
19	.00108814	4	.00103734	9	.000991080	4	.000948767
920	.00108696	5	.00103627	1010	.000990099	5	.000947867
1	.00108578	6	.00103520	11	.000989120	6	.000946970
2	.00108460	7	.00103413	12	.000988142	7	.000946074
3	.00108342	8	.00103306	13	.000987167	8	.000945180
4	.00108225	9	.00103199	14	.000986193	9	.000944287
5	.00108108	970	.00103093	15	.000985222	1060	.000943396
6	.00107991	1	.00102987	16	.000984252	1	.000942507
7	.00107875	2	.00102881	17	.000983284	2	.000941620
8	.00107759	3	.00102775	18	.000982318	3	.000940734
9	.00107643	4	.00102669	19	.000981354	4	.000939850
930	.00107527	5	.00102564	1020	.000980392	5	.000938967
1	.00107411	6	.00102459	1	.000979432	6	.000938086
2	.00107296	7	.00102354	2	.000978474	7	.000937207
3	.00107181	8	.00102250	3	.000977517	8	.000936330
4	.00107066	9	.00102145	4	.000976562	9	.000935454
5	.00106952	980	.00102041	5	.000975610	1070	.000934579
6	.00106838	1	.00101937	6	.000974659	1	.000933707
7	.00106724	2	.00101833	7	.000973710	2	.000932836
8	.00106610	3	.00101729	8	.000972763	3	.000931966
9	.00106496	4	.00101626	9	.000971817	4	.000931099
940	.00106383	5	.00101523	1030	.000970874	5	.000930233
1	.00106270	6	.00101420	1	.000969932	6	.000929368
2	.00106157	7	.00101317	2	.000968992	7	.000928505
3	.00106044	8	.00101215	3	.000968054	8	.000927644
4	.00105932	9	.00101112	4	.000967118	9	.000926784
5	.00105820	990	.00101010	5	.000966184	1080	.000925926

No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.
1081	.000925069	1126	.000888099	1171	.000853971	1216	.000822368
2	.000924214	7	.000887311	2	.000853242	17	.000821693
3	.000923361	8	.000886525	3	.000852515	18	.000821018
4	.000922509	9	.000885740	4	.000851789	19	.000820344
5	.000921659	1130	.000884956	5	.000851064	1220	.000819672
6	.000920810	1	.000884173	6	.000850340	1	.000819001
7	.000919963	2	.000883392	7	.000849618	2	.000818331
8	.000919118	3	.000882612	8	.000848896	3	.000817661
9	.000918274	4	.000881834	9	.000848176	4	.000816993
1090	.000917431	5	.000881057	1180	.000847457	5	.000816326
1	.000916590	6	.000880282	1	.000846740	6	.000815661
2	.000915751	7	.000879508	2	.000846024	7	.000814996
3	.000914913	8	.000878735	3	.000845308	8	.000814332
4	.000914077	9	.000877963	4	.000844595	9	.000813670
5	.000913242	1140	.000877193	5	.000843882	1230	.000813008
6	.000912409	1	.000876424	6	.000843170	1	.000812348
7	.000911577	2	.000875657	7	.000842460	2	.000811688
8	.000910747	3	.000874891	8	.000841751	3	.000811030
9	.000909918	4	.000874126	9	.000841043	4	.000810373
1100	.000909091	5	.000873362	1190	.000840336	5	.000809717
1	.000908265	6	.000872600	1	.000839631	6	.000809061
2	.000907441	7	.000871840	2	.000838926	7	.000808407
3	.000906618	8	.000871080	3	.000838222	8	.000807754
4	.000905797	9	.000870322	4	.000837521	9	.000807102
5	.000904977	1150	.000869565	5	.000836820	1240	.000806452
6	.000904159	1	.000868810	6	.000836120	1	.000805802
7	.000903342	2	.000868056	7	.000835422	2	.000805153
8	.000902527	3	.000867303	8	.000834724	3	.000804505
9	.000901713	4	.000866551	9	.000834028	4	.000803858
1110	.000900901	5	.000865801	1200	.000833333	5	.000803213
11	.000900090	6	.000865052	1	.000832639	6	.000802568
12	.000899281	7	.000864304	2	.000831947	7	.000801925
13	.000898473	8	.000863558	3	.000831255	8	.000801282
14	.000897666	9	.000862813	4	.000830565	9	.000800640
15	.000896861	1160	.000862069	5	.000829875	1250	.000800000
16	.000896057	1	.000861326	6	.000829187	1	.000799360
17	.000895255	2	.000860585	7	.000828500	2	.000798722
18	.000894454	3	.000859845	8	.000827815	3	.000798085
19	.000893655	4	.000859106	9	.000827130	4	.000797448
1120	.000892857	5	.000858369	1210	.000826446	5	.000796813
1	.000892061	6	.000857633	11	.000825764	6	.000796178
2	.000891266	7	.000856898	12	.000825082	7	.000795545
3	.000890472	8	.000856164	13	.000824402	8	.000794913
4	.000889680	9	.000855432	14	.000823723	9	.000794281
5	.000888889	1170	.000854701	15	.000823045	1260	.000793651

No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.
1261	.000793021	1306	.000765697	1351	.000740192	1396	.000716332
2	.000792393	7	.000765111	2	.000739645	7	.000715820
3	.000791766	8	.000764526	3	.000739098	8	.000715308
4	.000791139	9	.000763942	4	.000738552	9	.000714796
5	.000790514	1310	.000763359	5	.000738007	1400	.000714286
6	.000789889	11	.000762776	6	.000737463	1	.000713776
7	.000789266	12	.000762195	7	.000736920	2	.000713267
8	.000788643	13	.000761615	8	.000736377	3	.000712758
9	.000788022	14	.000761035	9	.000735835	4	.000712251
1270	.000787402	15	.000760456	1360	.000735294	5	.000711744
1	.000786782	16	.000759878	1	.000734754	6	.000711238
2	.000786163	17	.000759301	2	.000734214	7	.000710732
3	.000785546	18	.000758725	3	.000733676	8	.000710227
4	.000784929	19	.000758150	4	.000733138	9	.000709723
5	.000784314	1320	.000757576	5	.000732601	1410	.000709220
6	.000783699	1	.000757002	6	.000732064	11	.000708717
7	.000783085	2	.000756430	7	.000731529	12	.000708215
8	.000782473	3	.000755858	8	.000730994	13	.000707714
9	.000781861	4	.000755287	9	.000730460	14	.000707214
1280	.000781250	5	.000754717	1370	.000729927	15	.000706714
1	.000780640	6	.000754148	1	.000729395	16	.000706215
2	.000780031	7	.000753579	2	.000728863	17	.000705716
3	.000779423	8	.000753012	3	.000728332	18	.000705219
4	.000778816	9	.000752445	4	.000727802	19	.000704722
5	.000778210	1330	.000751880	5	.000727273	1420	.000704225
6	.000777605	1	.000751315	6	.000726744	1	.000703730
7	.000777001	2	.000750750	7	.000726216	2	.000703235
8	.000776397	3	.000750187	8	.000725689	3	.000702741
9	.000775795	4	.000749625	9	.000725163	4	.000702247
1290	.000775194	5	.000749064	1380	.000724638	5	.000701754
1	.000774593	6	.000748503	1	.000724113	6	.000701262
2	.000773994	7	.000747943	2	.000723589	7	.000700771
3	.000773395	8	.000747384	3	.000723066	8	.000700280
4	.000772797	9	.000746826	4	.000722543	9	.000699790
5	.000772201	1340	.000746269	5	.000722022	1430	.000699301
6	.000771605	1	.000745712	6	.000721501	1	.000698812
7	.000771010	2	.000745156	7	.000720980	2	.000698324
8	.000770416	3	.000744602	8	.000720461	3	.000697837
9	.000769823	4	.000744048	9	.000719942	4	.000697350
1300	.000769231	5	.000743494	1390	.000719424	5	.000696864
1	.000768639	6	.000742942	1	.000718907	6	.000696379
2	.000768049	7	.000742390	2	.000718391	7	.000695894
3	.000767459	8	.000741840	3	.000717875	8	.000695410
4	.000766871	9	.000741290	4	.000717360	9	.000694927
5	.000766283	1350	.000740741	5	.000716846	1440	.000694444

No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.
1441	.000693962	1486	.000672948	1531	.000653168	1576	.000634518
2	.000693481	7	.000672495	2	.000652742	7	.000634115
3	.000693001	8	.000672043	3	.000652316	8	.000633714
4	.000692521	9	.000671592	4	.000651890	9	.000633312
5	.000692041	1490	.000671141	5	.000651466	1580	.000632911
6	.000691563	1	.000670691	6	.000651042	1	.000632511
7	.000691085	2	.000670241	7	.000650618	2	.000632111
8	.000690608	3	.000669792	8	.000650195	3	.000631712
9	.000690131	4	.000669344	9	.000649773	4	.000631313
1450	.000689655	5	.000668896	1540	.000649351	5	.000630915
1	.000689180	6	.000668449	1	.000648929	6	.000630517
2	.000688705	7	.000668003	2	.000648508	7	.000630120
3	.000688231	8	.000667557	3	.000648088	8	.000629723
4	.000687758	9	.000667111	4	.000647668	9	.000629327
5	.000687285	1500	.000666667	5	.000647249	1590	.000628931
6	.000686813	1	.000666223	6	.000646830	1	.000628536
7	.000686341	2	.000665779	7	.000646412	2	.000628141
8	.000685871	3	.000665336	8	.000645995	3	.000627746
9	.000685401	4	.000664894	9	.000645578	4	.000627353
1460	.000684932	5	.000664452	1550	.000645161	5	.000626959
1	.000684463	6	.000664011	1	.000644745	6	.000626566
2	.000683994	7	.000663570	2	.000644330	7	.000626174
3	.000683527	8	.000663130	3	.000643915	8	.000625782
4	.000683060	9	.000662691	4	.000643501	9	.000625391
5	.000682594	1510	.000662252	5	.000643087	1600	.000625000
6	.000682128	11	.000661813	6	.000642673	2	.000624219
7	.000681663	12	.000661376	7	.000642261	4	.000623441
8	.000681199	13	.000660939	8	.000641848	6	.000622665
9	.000680735	14	.000660502	9	.000641437	8	.000621890
1470	.000680272	15	.000660066	1560	.000641026	1610	.000621118
1	.000679810	16	.000659631	1	.000640615	12	.000620347
2	.000679348	17	.000659196	2	.000640205	14	.000619578
3	.000678887	18	.000658761	3	.000639795	16	.000618812
4	.000678426	19	.000658328	4	.000639386	18	.000618047
5	.000677966	1520	.000657895	5	.000638978	1620	.000617284
6	.000677507	1	.000657462	6	.000638570	2	.000616523
7	.000677048	2	.000657030	7	.000638162	4	.000615763
8	.000676590	3	.000656598	8	.000637755	6	.000615006
9	.000676132	4	.000656168	9	.000637349	8	.000614250
1480	.000675676	5	.000655738	1570	.000636943	1630	.000613497
1	.000675219	6	.000655308	1	.000636537	2	.000612745
2	.000674764	7	.000654879	2	.000636132	4	.000611995
3	.000674309	8	.000654450	3	.000635728	6	.000611247
4	.000673854	9	.000654022	4	.000635324	8	.000610500
5	.000673401	1530	.000653595	5	.000634921	1640	.000609756

No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.	No.	Reciprocal.
1642	.000609013	1732	.000577367	1822	.000548848	1912	.000523012
4	.000608272	4	.000576701	4	.000548246	14	.000522466
6	.000607533	6	.000576037	6	.000547645	16	.000521920
8	.000606796	8	.000575374	8	.000547046	18	.000521376
1650	.000606061	1740	.000574713	1830	.000546448	1920	.000520833
2	.000605327	2	.000574053	2	.000545851	2	.000520291
4	.000604595	4	.000573394	4	.000545256	4	.000519750
6	.000603865	6	.000572737	6	.000544662	6	.000519211
8	.000603136	8	.000572082	8	.000544069	8	.000518672
1660	.000602410	1750	.000571429	1840	.000543478	1930	.000518135
2	.000601685	2	.000570776	2	.000542888	2	.000517599
4	.000600962	4	.000570125	4	.000542299	4	.000517063
6	.000600240	6	.000569476	6	.000541711	6	.000516528
8	.000599520	8	.000568828	8	.000541125	8	.000515996
1670	.000598802	1760	.000568182	1850	.000540540	1940	.000515464
2	.000598086	2	.000567537	2	.000539957	2	.000514933
4	.000597371	4	.000566893	4	.000539374	4	.000514403
6	.000596658	6	.000566251	6	.000538793	6	.000513874
8	.000595947	8	.000565611	8	.000538213	8	.000513347
1680	.000595238	1770	.000564972	1860	.000537634	1950	.000512820
2	.000594530	2	.000564334	2	.000537057	2	.000512295
4	.000593824	4	.000563698	4	.000536480	4	.000511770
6	.000593120	6	.000563063	6	.000535905	6	.000511247
8	.000592417	8	.000562430	8	.000535332	8	.000510725
1690	.000591716	1780	.000561798	1870	.000534759	1960	.000510204
2	.000591017	2	.000561167	2	.000534188	2	.000509684
4	.000590319	4	.000560538	4	.000533618	4	.000509165
6	.000589622	6	.000559910	6	.000533049	6	.000508647
8	.000588928	8	.000559284	8	.000532481	8	.000508130
1700	.000588235	1790	.000558659	1880	.000531915	1970	.000507614
2	.000587544	2	.000558035	2	.000531350	2	.000507099
4	.000586854	4	.000557413	4	.000530785	4	.000506585
6	.000586166	6	.000556793	6	.000530222	6	.000506073
8	.000585480	8	.000556174	8	.000529661	8	.000505561
1710	.000584795	1800	.000555556	1890	.000529100	1980	.000505051
12	.000584112	2	.000554939	2	.000528541	2	.000504541
14	.000583430	4	.000554324	4	.000527983	4	.000504032
16	.000582750	6	.000553710	6	.000527426	6	.000503524
18	.000582072	8	.000553097	8	.000526870	8	.000503018
1720	.000581395	1810	.000552486	1900	.000526316	1990	.000502513
2	.000580720	12	.000551876	2	.000525762	2	.000502008
4	.000580046	14	.000551268	4	.000525210	4	.000501504
6	.000579374	16	.000550661	6	.000524659	6	.000501002
8	.000578704	18	.000550055	8	.000524109	8	.000500501
1730	.000578035	1820	.000549451	1910	.000523560	2000	.000500000

CHAPTER III.

PROPORTION, PERCENTAGE AND ALLIGATION.

Proportion.

Computations of comparative values are problems which can usually best be solved by "proportion" or the **rule of three**. That arithmetical method is one by which we find an unknown fourth value from three known values of which the first bears the same ratio to the second as the third bears to the fourth. The unknown value (or the value sought) is usually designated as **x**. If we, then, designate the other values as **a**, **b** and **c**, we say that **a** bears the same ratio to **b** as **c** bears to **x**, or that **a** is to **b** as **c** is to **x**, and we write that statement as follows:

$$a:b::c:x$$

This is an equation; it expresses an equality of ratios.

Expressing the known values of **a**, **b** and **c** by numbers we still employ the same form of statement. Thus, if the value of **a** is 2, that of **b** 3, and that of **c** 4, we change the expression **a:b::c:x** to **2:3::4:x**, and we say that 2 is to 3 as 4 is to **x**, or that 2 bears the same proportion to 3 as 4 does to **x**. That

is equivalent to saying that $\frac{3}{2}$ is equal to $\frac{x}{4}$ and that $\frac{2}{3}$ is equal to $\frac{4}{x}$

The problem to be solved is to find the value of **x**.

Since 3 is $1\frac{1}{2}$ times 2, and 4 is to **x** as 2 is to 3, it follows that **x** must be $1\frac{1}{2}$ times 4. Therefore, **x** is 6.

Again, since 2 is $\frac{2}{3}$ of 3, it follows that 4 must be $\frac{2}{3}$ of **x**. Therefore **x** is 6.

As 4 is $\frac{2}{3}$ of **x** or, in other words $\frac{2}{3}$ times **x**, it is evident that 3×4 must be equal to 3 times $\frac{2}{3} \times x$ and

As $\frac{2}{3}$ of **x** is $\frac{2}{3}$ times **x**, and is equal to 4, and as 3×4 must, therefore, be equal to $\frac{2}{3} \times 3 \times x$, and as $\frac{2}{3} \times 3$ is 2 it follows

further that 3×4 is equal to $2 \times x$. As 3×4 is 12 and $2 \times x$ is also 12, it follows that x must be $\frac{12}{2}$ which is 6.

The statement $a:b::c:x$ is equivalent to $\frac{b \times c}{a} = x$.

If 2 pounds cost 3 dollars, 4 pounds must cost 6 dollars. These ratios of pounds to dollars and dollars to pounds, and of pounds to pounds and dollars to dollars may be stated as follows:

$$2:3::4:6 \text{ and } 4:6::2:3;$$

$$3:2::6:4 \text{ and } 6:4::3:2;$$

$$2:4::3:6 \text{ and } 3:6::2:4;$$

$$4:2::6:3 \text{ and } 6:3::4:2.$$

In all of these statements of proportion there are 4 terms. In the proportion $2:3::4:6$ the numbers 2 and 6 are the **extreme terms** or **extremes** and the numbers 3 and 4 are the **mean terms**, or the **means**. The first two numbers or terms form the **first couplet**, and the third and fourth form the **second couplet**.

The product obtained by multiplying the first term by the fourth, or by multiplying the extremes with each other, is in every problem the same as that obtained by multiplying the second term by the third, or by multiplying the means by each other. Thus:

$$2 \times 6 = 12 \text{ and } 3 \times 4 = 12;$$

$$4 \times 3 = 12 \text{ and } 6 \times 2 = 12; \text{ etc.}$$

Whenever any one of the four terms of a statement of proportion is unknown it may be represented by x instead of by a number. Thus we may have:

$$x:3::4:6 \text{ and } x:6::2:3;$$

$$2:x::4:6 \text{ and } 4:x::2:3;$$

$$2:3::x:6 \text{ and } 4:6::x:3;$$

$$2:3::4:x \text{ and } 4:6::2:x; \text{ etc.}$$

The problems are accordingly solved by the application of the following rules:

A. When both means and one of the extremes are known, divide the product of the means by the known extreme; the quotient is the value of x .

B. When both extremes and one of the means are known, divide the product of the extremes by the known mean; the quotient is the value of x .

The problem $x:3::4:6$ is solved as follows:

$$\frac{3 \times 4}{6} = 2.$$

The problem $x:6::2:3$ as follows:

$$\frac{6 \times 2}{3} = 4.$$

The problem $2:x::4:6$ as follows:

$$\frac{2 \times 6}{4} = 3.$$

The problem $4:x::2:3$ as follows:

$$\frac{3 \times 4}{2} = 6.$$

The problem $2:3::x:6$ is solved as follows:

$$\frac{2 \times 6}{3} = 4.$$

The problem $2:3::4:x$ as follows:

$$\frac{3 \times 4}{2} = 6.$$

It has been shown that the equality of the ratios may be correctly stated in several different ways and that whatever may be the form of statement adopted it will if correct lead to a right result. It makes no difference whether the unknown term (x) is the first, second, third or fourth term provided the known terms are correctly placed in their relations to it. But in actual practice it is a good rule to adopt a uniform method of writing the equation, as follows:

Always make x the fourth term: the third term should next be put down and is the known term of the same kind of value as x . The first couplet is then written, and the relative posi-

tions of its terms must be decided by the ratio of the third term to the fourth, for the "equality of ratios" demands that the first term shall bear the same ratio to the second term as the third term bears to x . If it is evident that the value sought (x) must be greater than the third term, then the second term must, of course, be greater than the first term in the same proportion; but if x must be smaller than the third term, then the second term must be in the same ratio smaller than the first term. Having written the equation in that order we work out the answer to the problem by dividing the product of the second and third terms by the first term.

The following examples will show how the equations are best stated:

1. If 2 pounds cost \$3 how much will 4 pounds cost?

The answer (x) to this problem must be dollars. Our third and fourth terms must, therefore, be $3:x$. As 4 pounds cost more than 2 pounds, x must be greater than \$3. Our equation must accordingly stand:

$$2:4::3:x$$

and we solve the problem by multiplying 4 by 3 and dividing the product by 2:

$$\frac{4 \times 3}{2} = 6.$$

2. If a train moves at the rate of 60 miles in 2 hours, how many miles will it run in 10 hours?

The equation here is:

2 hours is to 10 hours as 60 miles is to x miles, or $2:10::60:x$.

Therefore: $\frac{10 \times 60}{2} = 300$ miles.

3. If a train moves 60 miles in 2 hours, how many hours will it take that train to travel 30 miles?

Here x is to be hours. Hence the second couplet of the proportion must be $2:x$. Evidently the answer (x) must be less than 2 hours. The ratio of 2 to x must be the same as that of 60 to 30. Hence we write:

$$60:30::2:x$$

Therefore: $\frac{30 \times 2}{60} = 1$ hour.

4. If 2 men can dig 80 feet of ditch in 3 days how many feet can 3 men dig in the same number of days?

As the answer (x) is to be feet and greater than 80 our equation is

2 men is to 3 men as 80 feet is to x feet, or $2:3::80:x$.

$$\text{Solution: } \frac{3 \times 80}{2} = 120 \text{ feet.}$$

5. If 2 men can dig 80 feet of ditch in 3 days how many feet can they dig in 2 days?

Here x must be smaller than 80, and our equation is

$$3:2::80:x.$$

$$\text{Solution: } \frac{2 \times 80}{3} = 53\frac{1}{3} \text{ feet.}$$

6. If 2 men can dig 80 feet of ditch in 3 days how many feet can 3 men dig in 2 days?

Here we have examples 4 and 5 combined.

$$\left. \begin{array}{l} 2:3 \\ 3:2 \end{array} \right\} :: 80:x, \text{ or } \frac{3 \times 2 \times 80}{2 \times 3} = 80 \text{ feet.}$$

(See cancellation, p. 9.)

7. How many chairs at \$3 each should you get in exchange for 12 chairs at \$2 each?

In this problem it is evident that the ratio of \$2 to \$3 is not the same as that of 12 chairs to x chairs, but the opposite. Our equation must be:

$$3:2::12:x$$

8. How many pounds of acid of 40 per cent. strength are equivalent to 100 pounds of 50 per cent. acid?

The answer (x) must be more than 100 pounds. The quantities required of the two lots of acid must be inversely as their respective percentage strengths. Hence

$$40:50::100:x$$

(For an explanation of "per cent." referred to in examples 8, 9, 10 and 11, see p. 31.)

9. We know that 907.92 Gm of sulphuric acid of 10% strength must be used to produce 122.37 Gm of ammonium

sulphate. How much sulphuric acid of 92.5% strength must be used to produce the same quantity of the same salt?

Answer: $92.5 : 10 :: 907.92 : x$, or $\frac{10 \times 907.92}{92.5} = 98.15 \text{ Gm}$

10. As 907.92 Gm of sulphuric acid of 10% strength must be used to make 122.37 Gm of ammonium sulphate, how much sulphuric acid of 92.5% strength will be required to make 244.74 Gm of the same salt?

As the answer sought is the number of Gm of sulphuric acid our third and fourth terms will be 907.92 x . As a smaller quantity of 92.5% acid is required than of 10% acid we must make the first term greater than the second and therefore the first term will be 92.5 and the second term 10.

But it requires more acid to make 244.74 Gm of product than to make 122.37 Gm. Hence we make 122.37 the first term and 244.74 the second term of this ratio. Our equation will therefore stand—

$$\left. \begin{array}{l} 92.5 : 10 \\ 122.37 : 244.74 \end{array} \right\} :: 907.92 : x$$

The problem is solved as follows:

$$\frac{10 \times 244.74 \times 907.92}{92.50 \times 122.37} = 196.30 \text{ Gm}$$

11. To make 322 Gm of potassium citrate (100%) requires 208.50 Gm of citric acid (100%). How much of a 40% solution of citric acid will be required to make 600 Gm of a 15% solution of potassium citrate?

600 Gm of product requires more citric acid than 322 Gm.

A larger quantity of 40% solution of citric acid is required than of citric acid itself (100%).

A 100% product requires more citric acid than a 15% product.

Hence we shall have

$$\left. \begin{array}{l} 322 : 600 \\ 40 : 100 \\ 100 : 15 \end{array} \right\} :: 208.50 : x$$

The problem is accordingly :

$$\frac{600 \times 100 \times 15 \times 208.50}{322 \times 40 \times 100}$$

By cancellation (p. 9) we reduce the foregoing to

$$\frac{15 \times 15 \times 208.50}{322}$$

PERCENTAGE.

Proportion in arithmetic is a comparison of ratios. "Per cent." (%) is the ratio per hundred. All percentage problems are problems in proportion and can be solved as other problems in proportion are solved.

Units per cent are hundredths.

Four per cent. means 4 per hundred; 10% means 10 to the hundred; 1% means 1 in a hundred or **at the rate of 1 per centum** or 1 per hundred.

Four per cent. of \$100 is $\frac{4}{100}$ of \$100; 10% of one pound is $\frac{10}{100}$ of a pound; 3% of \$75 is $\frac{3}{100}$ of \$75; 25% of a population of 10,000 is $\frac{25}{100}$ of 10,000.

The reason for expressing the strength of solutions or mixtures or other substances in per cent. and for expressing profit or loss, interest or discount, or any other values or ratios in per cent., is the fact that our system of arithmetic is decimal and that the square of 10 lends itself more conveniently to this method of expression than any other power of 10 or the number 10 itself.

EXAMPLES.

1. What is 3% of 100?

$\frac{3}{100}$ of 100 is 3.

2. What is 80% of 100?

It is $\frac{80}{100}$ of 100 or 80.

3. What is 80% of 90?

It is $\frac{80}{100}$ of 90, or $\frac{80 \times 90}{100}$, or 72.

4. What % is 80 of 90?

$$80:90::x:100 \text{ or } 90:100::80:x.$$

Answer. $\frac{80 \times 100}{90}$, or $\frac{80}{90}$ of 100.

5. What % is 90 of 80?

It is $\frac{90}{80}$ of 100, or $\frac{90 \times 100}{80}$, for

$$90:80::x:100 \text{ or } 80:100::90:x.$$

6. Add 3% to 100 and state the sum.

Ans. $\frac{3}{100}$ of 100 is 3 and $100 + 3$ is 103.

7. Deduct 3% from 100 and state the remainder.

Ans. $100 - 3$ is 97.

8. What is 3% of 200?

Answer. $\frac{3}{100}$ of 200 is 6, for

$$100:200::3:x \text{ and } \frac{200 \times 3}{100} = 6.$$

9. Add 3% to 200 and state the sum.

Answer: $200 + \frac{200 \times 3}{100} = 206.$

10. What is 3% of 50?

Answer: $100:50::3:x$ or $\frac{50 \times 3}{100} = 1\frac{1}{2}.$

11. Deduct 4% from 50 and state the remainder.

$$50 - \frac{50 \times 4}{100} = 48.$$

12. What per cent. corresponds to the ratio of 3 to 30?

$$30:100::3:x \text{ or } \frac{100 \times 3}{30} = 10 \text{ per cent.}$$

Answer: 3 is 10 per cent. of 30.

13. If 30 pounds of Jalap contains 3 pounds of resin, how much resin is contained in 100 pounds?

30 pounds is to 100 pounds as 3 pounds is to x pounds, or

$$\frac{100 \times 3}{30} = 10 \text{ pounds.}$$

14. What is 6% interest on \$100?

Answer: \$6.

15. If you borrow \$500 for one year and return the sum with 7 per cent. interest, what is the total of principal and interest?

7% on \$500 is

100:500::7:x. or

$$\frac{500 \times 7}{100} = 35 \text{ dollars.}$$

As 7% interest means \$7 for each \$100, the interest on \$500 at the same rate is \$35.

Answer: \$535.

16. If you buy an article for \$15 and sell it for \$20 what % profit do you make?

Your profit is \$5; how many % does that correspond to?

15:100::5:x. or

$$\frac{100 \times 5}{15} = 33\frac{1}{3} \text{ per cent.}$$

17. What is the interest on \$130 for 6 months at 6% per annum?

$$\left. \begin{array}{l} 100:130 \\ 12:6 \end{array} \right\} ::6:x$$

Hence—

$$\frac{130 \times 6 \times \frac{3}{12}}{100 \times \frac{12}{2}} \text{ or } \frac{13 \times 3}{10} \text{ which is 3.9. Ans. \$3.90.}$$

18. A syrup is made of 12 pounds of sugar and 6 pounds of water. What is its % strength?

$$\frac{12}{3} : 100 :: \frac{12}{2} : x$$

$$\text{and } \frac{200}{3} = 66.66\%.$$

19. How much sugar and how much water must be used to make 18 pounds of syrup of 66.66% strength?

To find the quantity of sugar required to make 18 pounds of syrup of 66.66% strength is to solve the equation:

$$100:18::66.66:x$$

Hence we multiply 18 by 66.66 and divide the product by 100. The quotient is the quantity of sugar required. Subtracting that from 18 we find the quantity of water necessary.

20. How much salt must be added to 90 pounds of water to make a solution of 10% strength?

A solution of 10% strength is one containing 10 parts in 100, as 10 parts of salt together with 90 parts of water.

21. How much salt must be added to 80 pounds of water to produce a 10% solution?

$$90:80::10:x$$

Answer: $8\frac{8}{9}$ pounds.

22. How much 5% solution of silver nitrate can be made of 10 Gm of that salt?

$$5:10::100:x$$

Answer: 200 Gm.

23. How much water must be added to 10 Gm of silver nitrate to produce a 5% solution?

$$5:10::95:x$$

Answer: 190 Gm of water.

24. How much diluted acetic acid of 6% strength can be made out of 6 kilograms of the official "acetic acid" which is of 36% strength?

Evidently **a** multiplied by **b** must give the same product as **b** multiplied by **a**. Hence 6 kilograms of a 36% acid must contain the same quantity of absolute acid (100%) as 36 kilograms of a 6% acid for 6×36 is equal to 36×6 .

Therefore, we can make 36 kilograms of a 6% acid by adding 30 kilograms of water to 6 kilograms of the 36% acid.

25. How much water must be added to the stronger water of ammonia which is of 28% strength to make a 10% ammonia water?

10 lb of 28% solution must make 28 lb of 10% solution for the same reason that 2 five dollar bills make the same sum as 5 two dollar bills.

We therefore add 18 ounces of water to 10 ounces of the stronger water of ammonia to dilute it to 10% strength.

26. How many pounds of a 25% acid must be used as an equivalent to 30 pounds of a 10% acid of the same kind?

$$25:10::30:x$$

Answer: 12 pounds.

27. How many ounces of a 45% solution will be required to make 45 ounces of a 15% solution?

Answer: 15 ounces.

In Chapter II. on Reciprocals and their uses, p. 12, it was shown that to find the percentage (or proportion per 100) which any number bears to any other number we may multiply the reciprocal of the latter number by 100 times the first number.

Thus to find what per cent. 80 is of 125 multiply the reciprocal of 125 by 100 times 80. As the reciprocal of 125 is 0.008 and 100 times 80 is 8000 we find our answer to be 0.008×8000 or 64 per cent.

ALLIGATION IN PHARMACEUTICAL AND CHEMICAL PROBLEMS.

Alligation may be conveniently employed to find the proportions required of any number of constituents of different values to produce a mixture of any given intermediate value.

The simplest problems of this kind are those in which the constituents are but two, one of a higher and the other of a lower value than that of the product sought. In such a case the use of the constituent of a higher value increases the value of the product while the use of the other constituent diminishes that value. In order, therefore, to obtain a product of a given value the gain and the loss must offset each other. The following example will suffice to illustrate this:

Ex.—What proportions are required of a 15 per cent. solution and a 9 per cent. solution to produce a solution of 13 per cent. strength?

The difference between 15 and 13 is 2 and the gain resulting from the use of one part of the 15 per cent. solution is, there-

fore, 2. The difference between 9 and 13 is 4, and the loss resulting from the use of one equal part of the 9 per cent. solution is, therefore, 4. To equalize gain and loss it is only necessary to use 4 parts of the 15 per cent. solution and 2 parts of the 9 per cent. solution, or in other words to multiply the gain of 2 by 4 and the loss of 4 by 2, for $2 \times 4 = 4 \times 2$.

4 parts of solution of 15 per cent. strength and
 2 parts of solution of 9 per cent. strength must make
 —
 6 parts of solution of 13 per cent. strength

$$\text{for } 4 \times 15 = 60$$

$$2 \times 9 = 18$$

$$\begin{array}{r} 60 \\ 18 \\ \hline 78 \end{array}$$

$$\text{and } 6 \times 13 = 78.$$

Alligation may be employed to solve the following classes of problems:

1. To find the value of any mixture from the known values of the ingredients. See Rule I.

2. To find the proportional quantities of two ingredients of known value which must be used to produce a mixture of any given intermediate value. Rule II.

3. To find the quantity of an ingredient of known value which must be added to a fixed quantity of another ingredient of known value in order to produce a mixture of any desired intermediate value. Rule III.

4. To find the proportional quantities of any number of ingredients of different values which will produce a mixture of known value intermediate between the highest and lowest. Rule IV.

Rule I. To find the value of any mixture of known quantities of ingredients, each of known value:—**Multiply the quantity of each ingredient by its value and add the several products; divide the sum by the sum of the quantities of the several ingredients; the quotient is the value of the whole mixture.**

Ex.—We mix 3 lb of 80% alcohol, 8 lb of 91% alcohol, 5 lb

of 45.5% alcohol, 6 lb of 40% alcohol, and 8 lb of water; what will be the alcoholic percentage strength of the mixture?

$$\begin{array}{r}
 3 \times 80 = 240. \\
 8 \times 91 = 728. \\
 5 \times 45.5 = 227.5 \\
 6 \times 40 = 240. \\
 8 \times 0 = 0. \\
 \hline
 30 \qquad 1435.5 \\
 \text{and } \frac{1435.5}{30} = 47.85\%
 \end{array}$$

Rule II. To find the proportional quantities of any two ingredients of known values which must be used to produce a mixture of any given intermediate value: **The number of parts required of each ingredient is the difference between the value of the other ingredient and the desired value of the mixture to be produced.**

Let the value of the ingredient of higher value be designated as **A**, that of the ingredient of lower value as **B**, and the desired value as **C**. Then the process by which the answer is found will be based upon the fact that **C—B** parts must be used of the first ingredient and **A—C** parts of the second ingredient.

The customary method of stating the process is to place the value sought on the left of a vertical line and the values of the constituents on the right of that line, thus—

$$\begin{array}{c|c}
 13\% & \begin{array}{c} 15\% \\ 9\% \end{array}
 \end{array}$$

Then, as the difference between 13 and 9 is 4 we place the number 4 opposite 15, and as the difference between 13 and 15 is 2 we place that number opposite 9, thus—

$$\begin{array}{c|c}
 13\% & \begin{array}{c} 15\% - 4 \text{ parts.} \\ 9\% - 2 \text{ parts.} \end{array}
 \end{array}$$

When the constituents are more than two the principle involved in the process is the same for the proportions required are found for only two ingredients or constituents at a time as will be seen under the head of Rule IV.

Rule III. Having a known quantity of one ingredient of known value, and desiring to find the required quantity of the second ingredient of known value which must be used to produce a mixture of any desired mean value:—**Multiply the known quantity of the first ingredient by the difference between its value and the value desired; divide the product by the difference between the value of the second ingredient and the desired value of the mixture. The quotient is the quantity required of the second ingredient.**

Formula:—Let the known quantity of the first ingredient be called **a**; the difference between its value and the value desired, **b**; the difference between the value of the second ingredient and the value desired, **c**; and the quantity required of the second ingredient, **x**.

Then:—
$$\frac{a \times b}{c} = x$$

Ex. 1.—Suppose we have two ingredients, one of them of 90 per cent. value and the other 40 per cent., and desire to mix 10 pounds of the 90 per cent. ingredient with such an amount of the 40 per cent. ingredient as to produce a mean of 60 per cent.

Then: $\frac{10 \times 30}{20} = 15$, and therefore we will require 15 pounds of the 40 per cent. ingredient.

Proof:—

$$\begin{array}{r|l} 10 \times 90 = 900 & \\ \textcircled{15} \times 40 = 600 & 25 \\ \hline 25 & 1500 \\ & 150 \\ \hline & 1650 \end{array}$$

Ex. 2.—Suppose we have 10 pounds of an ingredient of 100 per cent. strength, and wish to dilute it to 50 per cent. strength. How much of a diluent of 0 per cent. strength is necessary?

$$\frac{10 \times 50}{50} = 10$$

Proof:—

$$\begin{array}{r|l} 10 \times 100 = 1000 & \\ 10 \times 0 = 0 & \\ \hline 20 & 1000 \\ & 100 \\ \hline & 50 \end{array}$$

Ex. 3.—Suppose we want to make a mixture of 40 per cent. strength out of 30 pounds of a diluent of 0 per cent. strength, by adding an ingredient of 100 per cent. strength.

Then:—

$$\frac{30 \times 40}{60} = 20$$

Proof:—

$$\begin{array}{r|l} 30 \times 0 = 0 & \\ 20 \times 100 = 2000 & \\ \hline 50 & 2000 \\ & 200 \\ \hline & 40 \end{array}$$

Ex. 4.—We have 10 pounds of a solution of 30 per cent. strength. How much water must be added to reduce it to 7 per cent.?

$$\frac{10 \times 23}{7} = \frac{230}{7} = 32\frac{2}{7} \text{ lb}$$

Proof:—

$$\begin{array}{r|l} 7 & 30 \times 7 = 210 \\ & 0 \times 23 = 0 \\ \hline & 30 \quad 210 \\ & \hline & 7 \\ & 30 \end{array}$$

$$7:10::30:x.$$

$$x = 42\frac{2}{7} \text{ lb.}$$

x is the number of pounds ($42\frac{2}{7}$) of 7 per cent. solution produced by 10 pounds of the 30 per cent. solution; the difference is the number of pounds of water required ($32\frac{2}{7}$ lb).

Ex. 5.—We have 20 pounds of a glycerin solution containing 7 per cent. of glycerin. We want to add to it enough glycerin to increase the strength to 30 per cent. How much glycerin must be added?

$$\frac{20 \times 23}{70} = \frac{460}{70} = 6\frac{4}{7}$$

Proof:—

$$\begin{array}{r|l}
 30 & \begin{array}{l} 7 \times 70 = 490 \\ 100 \times 23 = 2300 \\ \hline 93 \quad 2790 \\ 279 \end{array} \\
 & \begin{array}{r} 93 \\ \hline 30 \end{array}
 \end{array}$$

$$70:20::93:x.$$

$$x = 26 \frac{4}{7},$$

which is the number of pounds of 30 per cent. glycerin produced by adding $6 \frac{4}{7}$ lb glycerin to 20 lb of a mixture of glycerin and water containing 7 per cent. of glycerin.

Problems involving the mixing of more than two ingredients are, of course, uncommon; but when such problems occur they are most conveniently solved by alligation.

Rule IV. To find the proportions required of any number of ingredients of known value to produce a mixture of any desired intermediate value:

Write on the left of a vertical line the value sought, and on the right of that line the several values of the ingredients; link together the numbers expressing the respective values of any two of the ingredients one of which has a higher and the other a lower value than that sought until all of the several ingredients shall have been linked together in pairs; place opposite the value of each ingredient the difference between the value of the ingredient to which it is linked and the mean value sought; these differences are the proportions required of each of the ingredients.

Thus:—

14	{	9	2	=18
		12	4	=48
		13	2	=26
		16	1+5	=96
		18	2	=36
11+5=16			224	14
			16	
			64	
			64	
			—	

In the example above shown, we have 5 ingredients, one of the value of 9, another 12, another 13, another 16, and the fifth of 18; these 5 different ingredients are to be combined in such a manner as to produce a mixture of a mean value of 14.

The first ingredient, having a value of 9 (which is a value below 14), is linked to the fourth ingredient, having the value of 16 (which is above 14).

The second ingredient, with the value of 12, is linked to the fifth, with the value of 18; and the third ingredient, having a value of 13, is linked to the fourth in the same manner.

As the difference between 13 and 14 is 1, we place the number 1 opposite 16, to which the 13 is linked; and as the difference between 14 and 16 is 2, we place the number 2 opposite the 13 to which the 16 is linked.

Then, taking another pair, we put the number 4 opposite 12, because 12 is linked to 18, and the difference between 14 and 18 is 4; and opposite 18, which is linked to the 12, we put the number 2, which is the difference between 14 and 12.

One more pair now remains, viz.: that of 9 and 16. Opposite 9 we put the number 2, because 2 is the difference between 14 and 16 to which 9 is linked; and opposite 16 we put the number 5 (in addition to the number 1 already placed opposite 16), because 5 is the difference between 14 and 9.

Now we add together the numbers set opposite the ingredients, which are $11\frac{1}{2}$, making the total 16 parts. In other words, we must use 2 parts of the ingredient represented by 9; four parts of the ingredient having the value of 12; 2 parts of the third ingredient; $1\frac{1}{2}$, or 6 parts of the fourth ingredient, and 2 parts of the fifth, making 16 parts in all, and we will find that this mixture will have a mean value of 14.

Explanation:—Let us assume that the numbers 9, 12, 13, 16 and 18 represent percentage of strength; that, for instance, we have five different kinds of opium, one containing 9 per cent. morphine; the second 12 per cent.; the third 13 per cent.; the fourth 16 per cent.; and the fifth 18 per cent. of morphine, and we desire to mix these several kinds of opium in such a way as to produce an opium of 14 per cent. morphine. Now, as twice 9 per cent. is 18 per cent.; 4 times 12, 48 per cent.; twice 13 is 26; 6 times 16, 96; and twice 18 is 36 per

cent.; the total per cent. units will be 224, which, if divided by 16, gives us a mean of 14 as the quotient.

It is obvious that the preceding example just described may be solved in various other ways. Thus, for instance: We may link the 9 to the 18, instead of to the 16; we may link the 16 to the 12, instead of to the 13; and we may link the 13 to the 18, instead of to the 16. If we proceed in that manner the proportions of the ingredients will be somewhat different, but the final result, as to the mean value sought, will be the same. Thus:—

$$\begin{array}{rcl}
 14 \left[\begin{array}{l} 9 \\ 12 \\ 13 \\ 16 \\ 18 \end{array} \right] & \begin{array}{l} 4 \\ 2 \\ 4 \\ 2 \\ 5+1 \end{array} & \begin{array}{l} = 36 \\ = 24 \\ = 52 \\ = 32 \\ = 108 \end{array} \\
 & \hline
 17+1=18 & \left| \begin{array}{l} 252 \\ 18 \end{array} \right| & 14 \\
 & \hline
 & \begin{array}{l} 72 \\ 72 \end{array} & \\
 & \hline
 \end{array}$$

As 9 is linked to 18, we will require 4 parts of the 9 per cent opium, since the difference between 14 and 18 is 4. We will require at the same time 5 parts of the 18 per cent opium, since the difference between 14 and 9 is 5. If 4 parts of 9 per cent opium be mixed with 5 parts of 18 per cent opium, we will have:—

$$\begin{array}{l}
 4 \times 9 = 36 \\
 \frac{5 \times 18 = 90}{9 \quad 126} \text{ and } \frac{126}{9} = 14
 \end{array}$$

Then as 12 is linked to 16, we will require 2 parts of each of these 2 ingredients to obtain a mean value of 14 per cent, for:—

$$\begin{array}{l}
 2 \times 12 = 24 \\
 \frac{2 \times 16 = 32}{4 \quad 56} \text{ and } \frac{56}{4} = 14
 \end{array}$$

Next we deal with 13 and 18, which are linked together as the third pair. We will require 4 parts of the 13 per cent

opium, because the difference between 14 and 18 is 4; and we will require 1 part of the 18 per cent opium, because the difference between 14 and 13 is 1, for:—

$$\begin{array}{r} 4 \times 13 = 52 \\ \frac{1 \times 18 = 18}{5} \text{ and } \frac{70}{5} = 14 \end{array}$$

Since the mean produced by any one of the three pairs of ingredients in the proportion given above is 14, the mean of all of them will, of course, also be 14. As will be seen, the total number of parts of the five different kinds of opium is 18; and the percentages multiplied by these parts aggregate 252; and the total per cent divided by the total number of parts produces the average percentage 14.

To dilute or fortify any number of parts of any ingredient of given value, so as to produce any other given value:—**First find the relative quantities required of the ingredients, by Rule II or Rule IV, and then use proportion to ascertain the actual quantities required.** Thus:—Referring again to the first example, already given (under Rule IV.), suppose we have 50 pounds of opium of 9 per cent strength, and wish to fortify that opium with richer opiums to produce the average of 14, and we have for that purpose opiums of 12, 13, 16 and 18 per cent respectively; then, knowing that 2 pounds of 9 per cent opium will require 4 pounds of 12 per cent, 2 pounds of 13 per cent, 6 pounds of 16 per cent, and 2 pounds of 18 per cent, we can easily compute, by means of proportion, how much of each of the several stronger opiums will be required to fortify 50 pounds of 9 per cent opium to give it a mean of 14 per cent.

In the second example (under Rule IV.), we found that 4 pounds of 9 per cent opium required 2 pounds of 12 per cent opium, 4 pounds of 13 per cent, 2 pounds of 16 per cent, and 6 pounds of 18 per cent opium to produce 18 pounds of 14 per cent opium; and we can readily find, by means of proportion, how much of either of the other ingredients will be required to convert any number of pounds of 9 per cent opium into a 14 per cent opium, and can at the same time compute the total quantity of 14 per cent opium thus produced.

PART II.

WEIGHTS AND MEASURES.

CHAPTER I.

INTRODUCTORY.

The weights and measures employed for scientific purposes are almost universally those of the Metric System.

In medicine, pharmacy and chemistry the Metric System is used everywhere, and all pharmacopœias of the world employ it.

But in English-speaking countries the Metric System is not exclusively used. The Imperial System of Weights and Measures of Great Britain is used not only for all general purposes but also in science. In the United States the customary weights and measures are the old English systems which were brought over to America from England by the colonists but which were abolished in England by a law passed in 1824 to take effect January 1st, 1825.

The British Pharmacopœia is the only pharmacopœia in the world which uses any weights and measures other than those of the Metric System; it employs both the Metric and the Imperial weights and measures.

Medical and pharmaceutical literature, new and old, in America and England, refers to the old Apothecaries' Weights and Measures or to the units of the Imperial System, while all publications of other countries use the Metric System exclusively.

American physicians and pharmacists must accordingly be familiar with all these systems in order to be able to make ready and intelligent use of current literature and of reference works, and pharmacists must know them in order to understand all prescriptions.

In England the old medicinal fluid measures have disappeared entirely, but the drachm and the scruple are still written by British physicians and pharmacists, although the ounce and the pound are those of the Imperial System—the commercial or avoirdupois weight introduced eighty years ago. The grain fortunately remained unchanged so that its value is the same in all English-speaking countries.

But in America the medicinal weights have frequently been misnamed “troy.” Not only have the medicinal pound, ounce and grain been designated as the troy pound, troy ounce and troy grain, which is harmless since the values of the units named are identical in the two systems (medicinal weight and troy weight), but the drachm and scruple which belong exclusively to medicinal weights have been referred to as troy weight even in our pharmacopœias and other medical and pharmaceutical books, although the only units proper to troy weight are the pound, ounce, pennyweight and grain.

Since January 1. 1825, there have been no statutory standards of value of those old medicinal weights and measures either in England or America; but their traditional values have been maintained in America without any statutory provision therefor.

In 1878 Surgeon General Woodworth of the U. S. Marine Hospital Service, upon the recommendation of Acting Medical Purveyor Oscar Oldberg and with the approval of the Secretary of the Treasury John Sherman, issued an order making the use of the Metric System of Weights and Measures obligatory in that service. This was the first order adopted by any branch of the public service requiring the employment of the Metric System to the exclusion of any other measures. The order was at once carried into effect. Prescriptions were written in the Metric System by the medical officers, and all requisitions for supplies and all property returns were also made out in metric terms. Manufacturing pharmacists and chemists and wholesale druggists who submitted bids to furnish medical supplies were required to quote prices for metric quantities, and the medical purveying department of the Marine Hospital Service provided itself with metric contain-

ers which the glass manufacturers furnished as cheaply as any other bottles.

The medical department of the Navy adopted the metric system in 1880; and that of the Army in 1894, to take effect Jan. 1, 1895.

The Pharmacopœial Convention of 1880 ordered the Revision Committee to introduce the Metric System in the Sixth Revision of our Pharmacopœia, but in a very awkward and inconsistent manner. The gram and cubic-centimeter were ordered to be used to the exclusion of other terms in the official formulas for the preparation of fluid extracts, but "parts by weight" were to be employed in all other working formulas except those for pills and seidlitz powders, in which both the old and the new weights were to be used side by side. No wonder that this remarkable method proved to be decidedly unpopular. It satisfied neither the educated nor the uneducated. Accordingly ten years later the Metric System was adopted to the exclusion of all other weights and measures.

It is the universal custom to measure doses of liquid medicines with the aid of spoons, glasses, cups, etc. Small doses are quite generally ordered in terms of "drops." But tumblers, teacups, wineglasses, tablespoons, dessertspoons and teaspoons vary greatly in size, and "drops" are even more uncertain quantities. Physicians nevertheless order liquid remedies to be taken in doses of teaspoonfuls, dessertspoonfuls and stated numbers of drops. But not only do the spoons differ, but the person who pours the liquid may either be so over-cautious as to not fill the spoon in order to avoid spilling or may more than fill it, especially if cautious enough to hold the spoon over a tumbler or a cup in filling it. Every experienced pharmacist knows, too, that a convex surface of the liquid in the spoon, or in other words literally a "heaping spoonful" of a cohesive liquid is by no means an impossibility but rather a common occurrence. A "teaspoonful" measured in a small teaspoon not quite filled is a very different quantity from the heaping teaspoonful resulting from overfilling a large teaspoon. Prescriptions sometimes order "a small teaspoonful," or "a large dessertspoonful," etc., but this direction by the prescriber rather aggravates than relieves the difficulty.

With regard to the "drops," it must be admitted that even the practiced pharmacist, who should be an expert, finds it extremely difficult if not impossible to produce drops of uniform size, and to count them, even when he uses the best dropping instrument that can be made and observes all necessary precautions as to temperature and other conditions affecting the result. These recognized facts account for the directions in the pharmacopœias which prescribe the precise manner in which small amounts of liquid ingredients of mixtures shall be measured by the dispenser when ordered by the prescriber in such uncertain units as drops. In fact, quantities of liquids less than one cubic-centimeter should not be prescribed or dispensed in drops nor by fluid measure; they should be measured only by weight. To order the doses of liquids to be apportioned by counted drops is still more objectionable because the errors are not only proportionately greater as the quantities are less, but they are repeated each time a dose is taken and the person who drops the liquid and counts the drops is nearly always unaccustomed to such operations.

When liquids are prescribed the dose should, if practicable, be one that can be conveniently measured by any person with a reasonable degree of accuracy and uniformity. The medicine should accordingly be ordered so diluted that the dose will be not less than one-half (or still better a whole) **medicinal** teaspoonful.

Ordinary domestic liquid measures for medicines are:

- 1 tumblerful—from about 210 to 260 Cc. or 7 to over 8 fluid-ounces.
- 1 teacupful—about 120 Cc. or 4 fluidounces.
- 1 wineglass—about 45 to 60 Cc. or $1\frac{1}{2}$ to 2 fluidounces.
- 1 tablespoonful—about 16 to 20 Cc. or 4 to 5 fluidrachms.
- 1 dessertspoonful—about 8 to 10 Cc. or 2 to $2\frac{1}{2}$ fluidrachms.
- 1 teaspoonful—about 4 to 5 Cc. or 1 to $1\frac{1}{4}$ fluidrachms.

Graduated medicine glasses differ, too. In countries where the Metric System is exclusively used (in all except the English-speaking countries) the medicine graduates supplied by

pharmacists to their customers are adjusted to the following equivalents:

A tablespoonful	20 Ce.
A dessertspoonful.....	10 Ce.
A teaspoonful	5 Ce.

But in America and Great Britain they are:

A tablespoonful	16 Ce.
A dessertspoonful	8 Ce.
A teaspoonful	4 Ce.

Whenever medicine is ordered to be taken in spoonful doses the pharmacist should, if possible, advise the customer to use a graduated medicine glass, and should show the buyer how to use it.

Our pharmacopœia should, as other pharmacopœias do, contain directions as to the proper method of attaining uniform results in dispensing quantities prescribed in drops, and should not give definitions of spoonfuls at variance with the average capacity of spoons in actual use the world over.

While it is true that small quantities of liquids (less than 1 Ce.) are more accurately measured by weight than by fluid measure it is not true that **all** quantities in prescriptions for liquid remedies must be expressed by weight in order to attain the most accurate results as to dosage, for the dose should always be poured into a graduated medicine glass. The practice in all English-speaking countries is to prescribe liquids by fluid measure and only solids by weight. In all other countries weights are employed for both liquids and solids, which is neither convenient nor accurate.

CHAPTER II.

THE METRIC SYSTEM.

This system of weights and measures is called the "metric" system because it is based primarily upon the linear unit called the **meter**, which is the length determined by the prototype platinum bar made by Borda of Paris and supposed to represent the forty-millionth part of the meridian. Borda's meter bar is called the Meter of the Archives. It is no longer used as a standard. But a copy of exactly the same value is now the actual standard. It is in the custody of the International Metric Bureau and copies of it have been furnished by that Bureau to all civilized nations. The meter of the International Metric Bureau and all the copies of it which are used as national standards are made of an alloy composed of nine-tenths platinum and one-tenth iridium.

The original mass standard of the Metric System was a kilogram weight of platinum (also made by Borda) called the Kilogram of the Archives. It was intended to represent the mass of one cubic-decimeter of water at 4°C. But the actual standard now used is the Kilogram of the International Metric Bureau, the value of which is identical with that of the original, and which is made of the same material as that employed in the construction of the standard meter. The national standard kilograms furnished to all countries by the International Metric Bureau are exact copies.

Only two material standards are required for any system of weights and measures—the linear standard and the mass standard.

The chief merits of the Metric System are these: 1. It is in perfect accord with our numeration system; 2. All of its units of value bear a simple relation to the primary linear unit and hence are related to each other in the most simple and rational manner.

The **primary units** of measurement of the Metric System are: 1. For linear measure, the **Meter**; 2. for surface measure, the **Are** which is the square upon ten meters, or, in other words, one hundred square meters; 3. for cubic measure, the **Stère** or cubic meter; 4. for smaller capacity or volume measures, the **Liter** which is (theoretically) the cube upon the tenth of the meter; and 5. for weights, the **Gram** which is (theoretically) the mass of one cubic-centimeter of water at 4°C.

All the **subordinate units** of the Metric System are decimal multiples or subdivisions of the primary units. A new unit with a new name is furnished by each successive decimal multiple and for each successive decimal subdivision of the principal unit until three units larger and three smaller than the primary unit have been provided. It follows that there are seven distinct units of length, seven units of surface measure, and seven units also of cubic measure, volume measure and weight. This creates a greater number of units of each kind of measurement than is necessary or useful; but only the convenient and useful units are actually employed.

The respective values of the subordinate units of the Metric System are indicated by **prefixes** attached to the names of the primary units. For multiples of the primary units these prefixes are derived from Greek numerals; for subdivisions of the primary units the prefixes are derived from Latin numerals. The prefixes of both kinds are:

- Deka—which means 10.
- Hekto—which means 100.
- Kilo—which means 1000.
- deci—meaning tenth.
- centi—meaning hundredth.
- milli—meaning thousandth.

Thus a Dekagram is 10 grams, a Hektoliter is 100 liters, a Kilometer is 1,000 meters, a decimeter is one-tenth of a meter, a centigram is one hundredth of a gram, and a milliliter is one thousandth of a liter.

The prefixes Deka, Hekto, and deci are rarely used and ought to be altogether discarded because they are unneces-

sary and a redundancy of units is burdensome. The prefix centi is frequently used but can be profitably discontinued. The prefixes Kilo and milli are sufficient for all purposes. To illustrate the uselessness of a multiplicity of units of any kind of value we may cite the common expressions eagle, dollar, dime, cent and mill, referring to American money; they are decimal in their progression. But we would not think of using five different units in our money computations, for experience convinces us that the dollar and the cent are amply sufficient.

Special units are employed whenever desirable for special purposes. Thus the unit called the micromillimeter or "micron," which is the thousandth part of the millimeter, is a very useful unit of length in microscopic measurements, and the "mill" is a convenient unit of American money for certain special purposes.

The metric terms are to be **pronounced** as if English words, with the exception that the word liter is pronounced **leeter** and the word stère like **stair**.

The **abbreviations** of the names of the metric units are unfortunately not uniform. The term meter has been written M and m; kilometer is written KM, Km, and km; milligram is written MG, mG, mGm, Mgm, mgm, and mg; cubic-centimeter is written Ce., cc and C. c., but the expression cm^3 is also used; etc.

The American pharmacopœia uses the abbreviations Mm for millimeter, Cm for centimeter, Ce. for cubic-centimeter, and Gm for gram. But the most common abbreviations employed by those who use the metric units most are: m for meter, cm for centimeter, mm for millimeter, Km for kilometer, l for liter, ml for milliliter, Kl for kiloliter, Gm for gram, mgm for milligram, cgm for centigram, and Ce. for cubic-centimeter. The sign or abbreviation Gm is preferred to gm or g because there is no danger that Gm may be mistaken for grain, while a carelessly written gm might be taken for gr or grs, and g might be misunderstood to mean grain or grains.

The term cubic-centimeter is commonly employed all over the world to designate the thousandth part of the liter; but this practice is evidently incorrect, for while the Ce. is **theoretically** identical in value with the ml, one is the thousandth

part of the cubic-decimeter or the cube upon the hundredth part of the meter and the other is the thousandth part of the volume of one kilogram of water at 4°C **in vacuo**, and a Ce. of water is more than a ml, because the actual standard kilogram is light.

The **theoretical meter** is a ten-millionth part of the quadrant.

The **actual meter** is the meter defined by the "line-standard" called the standard Meter of the International Metric Bureau.

The **theoretical liter** is the cubic-decimeter.

The **actual liter** is the volume at 4°C . of one actual kilogram of water.

The **theoretical kilogram** is the mass of one cubic-decimeter of water at 4°C .

The **actual kilogram** is the mass of the standard kilogram of irido-platinum of the International Metric Bureau.

The cubic-centimeter is the thousandth part of the theoretical liter; but the milliliter is the thousandth part of the actual liter.

Besides the scientific theoretical liter and the scientific actual liter we have also the standard laboratory liter which is the volume of one kilogram of water **in air** at 15°C ., and the practical working liter of pharmacy and other technical pursuits which is the volume of one kilogram of water **in air** at about 20°C .

TABLES

of

WEIGHTS AND MEASURES OF THE METRIC SYSTEM.

1. Long Measure.

1 kilometer=1,000 meters.

1 hektometer=100 meters.

1 dekameter=10 meters.

1 meter

1 decimeter=0.1 meter.

1 centimeter=0.01 meter.

1 millimeter=0.001 meter.

2. Surface Measure.

1 hektare=100 ares, or 10,000 square meters.

1 are=100 square meters.

1 centiare=0.01 are, or 1 square meter.

3. Cubic Measure.

The **stère** is equal to 1 cubic meter or 1,000 cubic-decimeters.

1 cubic-decimeter=1,000 cubic-centimeters.

4. Capacity Measures.

1 kiloliter=1,000 liters.

1 hektoliter=100 liters.

1 dekaliter=10 liters.

1 liter

1 deciliter=0.1 liter.

1 centiliter=0.01 liter.

1 milliliter=0.001 liter.

5. Measures of Weight.

1 kilogram=1,000 grams.

1 hektogram=100 grams.

1 dekagram=10 grams.

1 gram

1 decigram=0.1 gram.

1 centigram=0.01 gram.

1 milligram=0.001 gram.

EXERCISES.**A. Linear Measure.**

1.—Give the number of millimeters in one kilometer.

2.—Give the number of millimeters in one meter.

3.—Give the number of millimeters in five meters.

- 4.—Give the number of millimeters in one-half meter.
 - 5.—Give the number of millimeters in one-tenth meter.
 - 6.—Give the number of millimeters in three-tenths meter.
 - 7.—State the number of micromillimeters in one millimeter.
-
- 8.—Reduce 103.072 meters to millimeters.
 - 9.—Reduce 0.0001 meter to millimeters.
 - 10.—Reduce 1.0303 meters to millimeters.
 - 11.—Reduce 0.404 centimeter to millimeters.
 - 12.—Reduce 0.1 meter to millimeters.
 - 13.—Reduce 0.2 meter to millimeters.
 - 14.—Reduce 0.0001 kilometer to millimeters.
 - 15.—Reduce 0.100101 meter to millimeters.
-
- 16.—Reduce 110.110 millimeters to kilometers.
 - 17.—Reduce 1101.01 centimeters to kilometers.
 - 18.—Reduce 0.700 decimeter to kilometers.
 - 19.—Reduce 10,000 decimeters to kilometers.
 - 20.—Reduce 10,000 meters to kilometers.
 - 21.—Reduce 10,000 centimeters to meters.
 - 22.—Reduce 10,000 millimeters to meters.
 - 23.—Reduce 0.01 kilometer to meters.
 - 24.—Reduce 103.405 centimeters to meters.
 - 25.—Reduce 0.270 meter to millimeters.
 - 26.—Reduce 10.04001 millimeters to meters.
 - 27.—Reduce 3.45 meters to millimeters.
 - 28.—Reduce 345 millimeters to meters.
 - 29.—Write **in figures**:—Thirteen millimeters, in meter units.
 - 30.—Write **in figures**:—Eleven centimeters, in meter units.
 - 31.—Write **in figures**:—Two hundred and seven meters, in centimeter units.
 - 32.—Write **in figures**:—One-half kilometer, in meters.
 - 33.—Write **in figures**:—One thousand and five millimeters, in centimeters.
 - 34.—Write **in figures**:—One thousand and five centimeters, in millimeters.
 - 35.—Add together:—One million micromillimeters, 75 millimeters, 75 centimeters, 4 dekameters, 4 decimeters, 0.004 kilometer, 13 hektometers, and 4.13 meters, and state the sum in meters.

B. Surface Measure.

36.—State the number of square-meters contained in the are.

37.—What is the other title of the square-dekameter in the Metric System?

38.—What other name is given to the square meter?

39.—State the number of centiares in the hektare.

40.—State the number of ares in the hektare.

41.—State the number of centiares in the are.

42.—How many square-meters in one square dekameter?

43.—How many square-meters in one square-kilometer?

44.—How many square-centimeters in one square-meter?

45.—How many square-millimeters in one square-centimeter?

46.—Reduce 23.05 square-millimeters to square-centimeters.

47.—Reduce 30,000 square-centimeters to square-meters.

48.—Reduce 50,000 square-meters to square-kilometers.

49.—Reduce 25 square kilometers to ares.

50.—Reduce 100 square-kilometers to hektares.

51.—Add together:—300 centiares, 3 ares, 30 hektares, 0.3 square kilometer, 3,000 square-centimeters, 30 square-decimeters, 3 square dekameters, 3,000 square-millimeters, and 0.03 square-hektometer, and state the sum in square-meters.

C. Cubic Measure and Measures of Capacity.

52.—State the number of cubic-centimeters in one cubic-decimeter.

53.—State the number of cubic-millimeters in one cubic-centimeter.

54.—State the number of cubic-meters in a cubic-kilometer.

55.—State the number of cubic-centimeters in one cubic-meter.

56.—What other name is applied to the cubic-meter?

57.—What other name is applied to the cubic-decimeter?

58.—How many cubic-decimeters are contained in one cubic-meter?

59.—How many stères are contained in one liter?

60.—How many stères in one kiloliter?

61.—How many milliliters in one stère?

- 62.—How many cubic-centimeters in one liter?
63.—How many milliliters in one liter?
64.—How many ml in $\frac{1}{2}$ of $\frac{1}{4}$ of 0.024 liter?
65.—Reduce 1,040.401 milliliters to liters.
66.—Reduce 3.004 cubic-decimeters to ml.
67.—Reduce 140.03 liters to ml.
68.—Reduce 0.0002 liter to ml.
69.—Reduce 15,432 ml to cubic-decimeters.
70.—Reduce 304 centiliters to ml.
71.—Write in figures:—Five thousand and seven ml, in deciliters.
72.—Write in figures:—Twenty-five hundred milliliters, in liters.
73.—Write in figures:—Two thousand and thirteen centiliters, in ml.
74.—Write in figures:—One-half milliliter.
75.—Add:—4 liters and 40 milliliters, and state the sum in ml.
76.—Subtract 3,456 ml from 5 liters, and state the remainder.
77.—Add together:—1 stere, 3 kiloliters, 5 cubic-meters, 5 liters, 0.5 dekaliter, 0.05 hektoliter, 0.005 kiloliter, 10 deciliters, 1,000 milliliters, 100 centiliters, and 5 cubic-decimeters, and state the sum in Ce.
78.—Subtract 1 ml from 10 liters and state the remainder in liters.
79.—Subtract 10 milliliters from 1 liter, and state the remainder in Ce.

D. Weight.

- 80.—State the number of grams in one kilogram.
81.—State the number of grams in one centigram.
82.—State the number of centigrams in one gram.
83.—State the number of milligrams in one kilogram.
84.—Reduce 0.048 Gm to milligrams.
85.—Reduce 35.005 centigrams to milligrams.
86.—Reduce 0.07005 kilogram to milligrams.
87.—Reduce 7.4008 Gm to milligrams.
88.—Reduce 0.0123 gram to milligrams.

- 89.—Reduce 0.123 gram to milligrams.
- 90.—Reduce 7,093.307 centigrams to Gm.
- 91.—Reduce 0.07 milligram to Gm.
- 92.—Reduce 0.00306 kilogram to Gm.
- 93.—Reduce 304.5 milligrams to Gm.
- 94.—Write **in words**: 0.001 Gm, in Gm.
- 95.—Write **in words**: 0.0001 kilogram, in Gm.
- 96.—Write **in words**: 0.01 milligram, in Gm.
- 97.—Write **in words**: 0.100 Gm, in centigrams.
- 98.—Write **in figures**: 4 kilograms, in grams.
- 99.—Write **in figures**: 0.4 kilogram, in Gm.
- 100.—Write **in figures**: 0.003 Gm, in milligrams.
- 101.—Write **in figures**: 0.202 Gm, in centigrams.
- 102.—Write **in figures**: Eleven hundred centigrams, in Gm.
- 103.—Write **in figures**: One thousand and two milligrams, in Gm.
- 104.—Write 4 kilograms, 47 Gm, and 4 centigrams, in one sum, in Gm.
- 105.—Add together:—130 centigrams, 13 milligrams, 130 Gm, 13 kilograms, 1.30 dekagrams, and 0.013 hektogram, and state the sum in decigrams.
- 106.—Subtract 65 centigrams from 1 gram, and state the remainder in milligrams.
- 107.—How is the word gram abbreviated?
- 108.—Add together:—One kilogram and one milligram, and write the answer **in figures** and in grams.

CHAPTER III.

ENGLISH AND AMERICAN WEIGHTS AND MEASURES.

The British Imperial System of Weights and Measures.

This system of weights and measures was adopted in 1824 to take effect January 1, 1825.

The British standard yard is a linear unit equal to 0.91440183 meter.

The British pound is equal to 453.5924277 grams.

The British gallon is the volume of 10 pounds of water at 62° F. in air, under a barometric pressure of 30 inches.

It is also defined as equal to 277.274 cubic inches.

TABLES

of

BRITISH WEIGHTS AND MEASURES.

1. Long Measure.

1 mile (statute mile)=8 furlongs, or 320 rods, or 1,760 yards, or 5,280 feet.

1 furlong (**fur.**)=40 rods or poles, or 220 yards, or 660 feet.

1 rod (**rd**) or pole (**p.**)=5½ yards, or 16½ feet.

1 yard (**yd**)=3 feet, or 36 inches.

1 foot (**ft**)=12 inches.

1 geographical or nautical mile is equal to 1.1508 statute mile.

1 league (**lea.**)=3 geographical miles.

1 degree is 20 leagues or 60 geographical miles.

2. Surface Measure.

- 1 township (tp.)=36 square miles.
 - 1 square mile=640 acres.
 - 1 acre=4 roods, or 10 square chains, or 160 square rods, or 4,840 square yards, or 43,560 square feet.
 - 1 rood= $2\frac{1}{2}$ square chains, or 40 square rods (poles or perches), or 1,210 square yards, or 10,890 square feet.
 - 1 square chain=16 square rods, or 484 square yards, or 4,356 square feet.
-

- 1 square yard=9 square feet, or 1,296 square inches.
- 1 square foot=144 square inches.

3. Cubic Measures and Other Measures of Capacity.

- 1 cubic yard=27 cubic feet or 46,656 cubic inches.
- 1 cubic foot=1,728 cubic inches.
- 1 British ton=42 cubic feet.
- 1 Imperial bushel=4 pecks, or 8 gallons, or 32 quarts (or 2218.192 cubic inches).
- 1 peck=2 gallons, or 8 quarts.
- 1 gallon=4 quarts or 8 pints.
- 1 quart=2 pints (or 69.3185 cubic inches).
- 1 pint=4 gill's (or 17.329625 cubic inches).
- 1 gill=4.33240625 cubic inches.
- 1 Imperial gallon (C.)=8 pints or 160 fluidounces (or 277.274 cubic inches).
- 1 pint (O.)=20 fluidounces, or 160 fluidrachms, or 9,600 minims.
- 1 fluidounce (f3)=8 fluidrachms, or 480 minims.
- 1 fluidrachm (f3)=60 minims (M).

4. Weight.

(Commercial Weight. Avoirdupois Weight.)

- 1 pound (lb)=16 ounces, or 7,000 grains.
- 1 ounce (oz)=437 $\frac{1}{2}$ grains (gr.).

The Old British Weights and Measures Customarily Employed in America.

The linear units of the United States are the same as those of the Imperial System of Great Britain. But the yard of the United States is $\frac{3600}{3937}$ of the meter and the ultimate standard by which yard measures, foot rules, and other long measure instruments are verified is the American National Prototype Meter.

The surface measures and cubic measures are the same as in Britain.

Dry Capacity Measures.

(The Old Winchester Measure of England.)

- 1 bushel=4 pecks, or 8 dry gallons, or 32 dry quarts, or 2150.4 cubic inches.
- 1 peck=2 dry gallons, or 8 dry quarts, or 537.6 cubic inches.
- 1 dry gallon=4 dry quarts, or 8 dry pints, or 268.8 cubic inches.
- 1 dry quart=2 dry pints, or 67.2 cubic inches.
- 1 dry pint=33.6 cubic inches.

Commercial Liquid Measure. (The Old Wine Measure.)

- 1 hogshead (hhd)=2 barrels, or 63 gallons.
- 1 barrel (bbl)=31 liquid gallons.
- 1 liquid gallon (wine gallon)=4 liquid quarts, or 8 liquid pints, or about 231 cubic inches.*
- 1 liquid quart=2 liquid pints, or about 57.75 cubic inches.
- 1 liquid pint (wine pint)=4 gills, or 28.875 cubic inches.
- 1 gill=7.21875 cubic inches.

*The liquid gallon of America the volume of 3785.434 grams of water at the temperature of maximum density (4° C.) weighed in *vacuo*. The equivalent of 3785.434 grams in the customary weights is 58,148.1444 grains.

American Apothecaries' Fluid Measure. (Derived from the
"liquid gallon.")

- 1 gallon (C)=3 pints, or 128 fluidounces, or 61,440 minims.
- 1 pint (O)=16 fluidounces, or 128 fluidrachms, or 7,680 minims.
- 1 fluidounce (f℥)=8 fluidrachms, or 480 minims.
- 1 fluidrachm (fʒ)=60 minims (M).

Troy Weight.

(The Old English Troy Weight for weighing precious metals,
coin and jewelry.)

- 1 pound (lb.)=12 ounces, or 5,760 grains.
- 1 ounce (oz.)=20 pennyweights, or 480 grains.
- 1 pennyweight (pwt.)=24 grains (gr.).

American Apothecaries' Weight. (The Old English Apothe-
caries' Weight.)

- 1 pound (lb.)=12 ounces or 5,760 grains.
- 1 ounce (℥)=8 drachms, or 24 scruples, or 480 grains.
- 1 drachm (ʒ)=3 scruples or 60 grains.
- 1 scruple (ʒ)=20 grains (gr.).

The troy pound and the apothecaries' or medicinal pound
are of identical value.

The grain of commercial (avoirdupois) weight is the same
as troy grain and the apothecaries' grain.

EXERCISES.

- 109.—How many pints in the liquid gallon of America?
- 110.—How many pints in the British liquid gallon?
- 111.—How many pints in the American dry gallon?
- 112.—How many pints in the British dry gallon?
- 113.—How many pints in the Imperial gallon?

114.—How many fluidounces in the British medicinal pint?

115.—How many fluidounces in the Imperial pint?

116.—How many fluidounces in the American Apothecaries' pint?

117.—Which is larger, the American medicinal pint, or the British?

118.—Which is larger, the American fluidounce or the British?

119.—Which is larger, the American minim or the British?

120.—How many fluidrachms in an American apothecaries' fluidounce?

121.—How many cubic inches in an American apothecaries' fluidounce?

122.—How many Imperial gallons in one wine gallon?

123.—How many Imperial quarts in one wine quart?

124.—How many Imperial fluidounces in one American fluidounce?

125.—How many Imperial minims in one American minim?

126.—How many American fluidounces in one wine gallon?

127.—How many American fluidounces in an Imperial gallon?

128.—How many American fluidounces equal 16 Imperial fluidounces?

129.—How many American fluidrachms in 2.50 wine pints?

130.—How many American fluidrachms in 1.05 wine gallons?

131.—How many American fluidrachms in 0.125 American fluidounces?

132.—How many Imperial fluidounces in one Imperial gallon?

133.—How many Imperial fluidounces in one wine gallon?

134.—How many American fluidounces equal 100 Imperial fluidounces?

135.—Write the symbols used for the fluidounce, the fluidrachm, and the minim, of American apothecaries' fluid measure.

136.—Write the symbols used to designate the fluidounce, fluidrachm, and minim, of British apothecaries' fluid measure.

137.—Write the sign used to designate the medicinal gallon, and the sign used to designate the medicinal pint.

138.—What is the commercial weight of the Imperial system?

139.—What is the customary commercial weight of America?

140.—What is the basis of the avoirdupois-pound?

141.—How is the avoirdupois-pound subdivided?

142.—How many drachms in the avoirdupois-ounce?

143.—How many ounces in the avoirdupois-pound?

144.—How many grains in the avoirdupois-pound?

145.—How many grains in the Imperial-pound?

146.—How many grains in the American commercial pound?

147.—How many grains in the troy-pound?

148.—What is the basis of troy-weight?

149.—How many ounces in a troy-pound?

150.—What is the medicinal ounce of America?

151.—How is the troy-ounce subdivided?

152.—How is the apothecaries' ounce subdivided?

153.—What is the medicinal ounce of the Imperial system?

154.—How many drachms in the English medicinal ounce?

155.—How many grains in the English medicinal ounce?

156.—What weights and measures are used for weighing gold and silver?

157.—What is a pennyweight?

158.—What is a scruple?

159.—What is the difference between the English scruple and the American scruple?

160.—Write the symbols for the American apothecaries' ounce, drachm, scruple, and grain.

161.—How many apothecaries' ounces in 100 avoirdupois-ounces?

162.—How many American apothecaries' ounces in one avoirdupois-pound?

163.—How many avoirdupois-ounces equal 24 apothecaries' ounces?

CHAPTER VI.

EQUIVALENTS OF THE UNITS OF EACH SYSTEM IN UNITS OF ANOTHER.

The following standard values are recognized:

1 Meter=39.3700 inches.

1 Kilogram=15,432.35639 grains.

1 Cubic-decimeter=61.023377953 cubic inches.

1 Square Meter=1,549.9969 square inches.

1 Yard=0.91440183 meter.

1 Pound (commercial)=453.5924277 Gm.

1 Avoirdupois or Commercial Ounce=28.3495267 Gm.

1 Medicinal or Apothecaries' Ounce=31.10348076 Gm.

1 Grain=64.79891825 milligrams.

1 Liter (the volume of one kilogram of water at 4° C. **in vacuo**)=1,000 Gm.

1 American Liquid Gallon ("wine gallon") of water at 4°C. **in vacuo**=3,785.4341 Gm. or 58,418.1444 grains.

1 Imperial Gallon of water at 62°F. in air of the same temperature=45,359.24277 Gm. (10lb).

If the cubic-decimeter and the actual Liter were identical volumes 1 cubic inch of water at 4°C. **in vacuo** would weigh 252.8925292 grains. But Schueckburg and Kater determined the weight of water experimentally with great care and found that 1 cubic inch of it at 62°F. **in vacuo** weighs 252.724 grains.

1 Liter of dry air, at 0°C., Bar. 760 mm, weighs 1.293030 Gm (or 19.9544998 grains).

The co-efficient of expansion of air is 0.003665 ($\frac{1}{273}$) for each degree C.

1 American Fluidounce of water at 62°F. in air weighs 455.382 grains.

USEFUL APPROXIMATE EQUIVALENTS.

- 1 Meter=40 inches.
- 1 inch=25 millimeters.
- 1 cubic-decimeter=60 cubic inches.
- 1 liter=34 American medicinal fluidounces.
- 1 cubic-centimeter=16 American minims.
- 1 American liquid quart=0.95 liter.
- 1 American fluidounce=30 cubic-centimeters.
- 1 American fluidounce=500 British minims.
- 1 Kilogram=2.2 commercial pounds.
- 1 Kilogram=35 commercial ounces.
- 1 Kilogram=32 American medicinal ounces.
- 1 Gram=15 or 16 grains.
- 1 American medicinal ounce=32 Gm.
- 1 commercial ounce=28.35 Gm.
- 1 drachm=4 Gm.
- 1 grain=64 milligrams.
- 96 American fluidounces of water weighs 100 commercial ounces.

SPECIFIC DENSITIES OF METALS OF WHICH WEIGHTS ARE MADE.

The brass of which weights are made usually has a specific density of 8.3.

Platinum has the specific density 21.46.

Silver has the specific density 10.6.

Aluminum has the specific density 2.5.

EXERCISES.

- 164.—State the equivalent of 3.03 meters in English inches.
- 165.—State the equivalent of 3.03 millimeters in English inches.
- 166.—State the equivalent of 0.303 centimeter in inches.
- 167.—State the equivalent of 4 inches in millimeters.
- 168.—State the equivalent of one foot in millimeters.
- 169.—State the equivalent of 0.01 inch in millimeters.

170.—How many centimeters equal one inch?

171.—How many centimeters equal 4 feet?

172.—How many centimeters equal 0.1 inch?

173.—State the difference in length between the yard and the meter, in inches.

174.—State the difference in length between the yard and the meter, in centimeters.

175.—State the exact equivalent of the meter, in American inches.

176.—State the exact equivalent of the yard, in meters.

177.—How many millimeters equal one inch?

178.—How many centimeters equal one inch?

179.—How many inches equal 100 millimeters?

180.—How many meters equal one mile?

181.—How many meters equal $7\frac{1}{2}$ yards?

182.—How many meters equal 144 inches?

183.—How many square-feet are contained in a rectangular area 2 feet wide and 30 inches long?

184.—How many square-inches of surface has a cube measuring 2 inches in each direction?

185.—How many square-centimeters of surface has a block 60 millimeters long, 30 millimeters wide, and 20 millimeters thick?

186.—How many square-inches equal one square-meter?

187.—Reduce 0.03 square-feet to square-centimeters.

188.—Reduce one acre to square-meters.

189.—Reduce 1 hektare to acres.

190.—Reduce 2 square miles to square-kilometers.

191.—Add one square-kilometer, one square-meter, and one square-centimeter, and state the sum in square-meters.

192.—Add one square-foot, 12 square-inches, and $\frac{1}{4}$ square-yard, and state the sum in square-feet.

193.—How many cubic-inches are contained in a block 6 inches long, 5 inches wide, and 4 inches thick?

194.—How many wine gallons equal one cubic-foot?

195.—How many cubic-feet of space in a room $12 \times 15 \times 10$ feet?

- 196.—State the equivalent of one cubic-meter, in liters.
- 197.—State the equivalent of one American liquid-gallon, in milliliters.
- 198.—State the equivalent of one liter, in cubic-inches.
- 199.—State the equivalent of one cubic-inch, in cubic-centimeters.
- 200.—How many ml in one wine gallon?
- 201.—How many ml in one American fluidounce?
- 202.—How many ml in an Imperial fluidounce?
- 203.—How many ml in an Imperial gallon?
- 204.—How many ml equal 60 American minims?
- 205.—How many ml equal 60 Imperial minims?
- 206.—How many cubic-inches equal 1101 milliliters?
- 207.—How many American minims equal 4.04 ml?
- 208.—How many minims equal 0.05 liter?
- 209.—How many American minims equal 15 ml?
- 210.—How many American minims equal one milliliter?
- 211.—How many cubic-centimeters equal 300 Imperial minims?
- 212.—How many liters equal 5 wine-pints?
- 213.—How many liters equal 6 Imperial pints?
- 214.—How many liters equal 100 American fluidounces?
- 215.—How many liters equal 100 Imperial fluidounces?
- 216.—How many Imperial minims equal 0.10 liter?
- 217.—How many Imperial minims equal one ml?
- 218.—How many Imperial fluidounces equal one wine-gallon?
- 219.—How many Imperial fluidounces equal one liter?
- 220.—How many ml equal one dry quart?
- 221.—How many ml equal one wine-quart?
- 222.—How many ml equal one Imperial quart?
- 223.—How many Gm equal one avoirdupois-pound?
- 224.—How many Gm equal one troy-pound?
- 225.—How many Gm equal one avoirdupois-ounce?
- 226.—How many Gm equal an apothecaries' ounce?
- 227.—How many Gm equal a troy-ounce?
- 228.—State the exact equivalent of the Gm in grains.
- 229.—State the equivalent of the grain in milligrams.
- 230.—How many Gm equal 6 avoirdupois-ounces?
- 231.—How many Gm equal 9 troy-ounces?

- 232.—How many Gm equal 5.50 avoirdupois-pounds?
 233.—How many Gm equal 0.50 avoirdupois-pounds?
 234.—How many Gm equal 500 grains?
 235.—How many grains equal 100,000 Gm?
 236.—How many grains equal one centigram?
 237.—State the equivalent of the decigram in grains.
 238.—State the equivalent of the milligram in grains.
 239.—State the equivalent of 65 milligrams in grains.
 240.—How many avoirdupois-ounces equal 0.40 kilogram?
 241.—How many avoirdupois-ounces equal 453 Gm?
 242.—How many avoirdupois-ounces equal 100 troy-ounces?
 243.—How many apothecaries' ounces equal one avoirdupois-pound?
 244.—How many apothecaries' ounces equal one kilogram?
 245.—How many apothecaries' ounces equal 100 avoirdupois-ounces?
 246.—How many apothecaries' ounces equal 373 Gm?
 247.—State the equivalent of 100 grains in milligrams.
 248.—State the equivalent of 1,000 grains in milligrams.
 249.—State the equivalent of one grain in mgm.
 250.—State the equivalent of 10 grains in Gm.
 251.—State the equivalent of 3 grains in mgm.
 252.—State the difference between 32 troy-ounces and one kilogram in grains.
-

253.—Add together:— 5ij , 3iij , 5ix , 9ij , and 3xvj , and give the sum in grains.

254.—Add together:—12 oz, 3iv , and $\frac{1}{2}$ lb, and give the answer in grains.

255.—Subtract 9ijss from 1 oz, and give the answer in grains.

256.—Add together:—Oss, f3vj , Cj, f5x , and mC , and give the answer in minims.

257.—State the quantities required of each of the following named ingredients to make 24 pills, each pill containing $\frac{1}{10}$ gr. extract of belladonna, $\frac{1}{2}$ gr. Aloin, $\frac{1}{60}$ gr. strychnine, and 1 gr. extract of rhamnus purshiana.

258.—State the quantities required of each of the following named ingredients to make one pint of an elixir, of which each fluidrachm is to contain 1 gr. quinine, $\frac{1}{100}$ gr. strychnine, and 2 gr. soluble phosphate of iron.

259.—What is the weight in air of one cubic-inch of water at 62° F., in grains?

260.—What is the weight in Gm of one ml of water, at maximum density in vacuo?

261.—What is the weight of one liter of water?

262.—What is the weight of one deciliter of water?

263.—What is the weight, in grains, of one American fluidounce of water?

264.—What is the weight, in troy-ounces, of one liter of water?

265.—What is the weight, in avoirdupois-ounces, of 96 American fluidounces of water?

266.—What is the weight, in avoirdupois-ounces, of 3 wine-pints of water?

267.—What is the weight, in grains, of one ml of water at 22° C.?

268.—What is the weight of 24 American fluidounces of water in avoirdupois-ounces?

269.—What is the weight of an American minim of water in grains?

270.—State the weight of an American fluidrachm of water in drachms.

271.—State the weight of an American fluidounce of water in apothecaries' ounces.

272.—State the weight of an Imperial pint of water in avoirdupois-ounces.

273.—What is the weight of an Imperial minim of water in grains?

274.—What is the weight of an Imperial fluidounce of water in grains?

275.—What is the weight of an Imperial gallon of water at 62° F., in air?

276.—What is the volume of 5 avoirdupois-pounds of water at 62° F., expressed in Imperial pints?

277.—What is the volume of 1 apothecaries' ounce of water in American fluidounces?

278.—What is the volume of 1 grain of water in American minims?

279.—What is the volume of 1 grain of water in Imperial minims?

CHAPTER VII.

DOSES.

Physician and pharmacist must have ready and reliable command of posology and must be able to mentally compute the quantities required for any number of doses, the number and size of doses contained in any given quantity of medicine, and other similar problems.

A person unable to calculate quickly and correctly the size of each single dose of each active ingredient ordered in a prescription, and the total amount ordered to be taken in a day, is unfit to be a dispenser, for one of the most important duties of a dispenser is to discover possible dangerous errors in the prescriptions he is called upon to fill, as well as to avoid making any errors himself.

The exercises in this chapter are purely arithmetical.

All doses are arbitrary and subject to great variation. The physician alone must be the judge in each individual case. But the dispenser must, nevertheless, satisfy himself that no serious error has been made and that he correctly understands the prescription before he dispenses it. The prescriber and the patient are both entitled to the protection which an intelligent scrutiny of the doses affords.

The doses mentioned in the pharmacopœias and in works upon medicine are either the average adult doses, as in the American Pharmacopœia of 1905, or maximum adult doses, as in the tables of maximum doses of dangerous remedies in the German and many other pharmacopœias, or the least as well as the greatest **customary** adult doses. The least customary dose for adults as generally stated is about $\frac{1}{4}$ or $\frac{1}{2}$ of the greatest customary dose. But the maximum safe doses are of special importance to the dispenser.

Doses administered by way of the mouth differ decidedly from those administered hypodermically and by the rectum.

Doses administered by hypodermatic injection are usually only one-half of the quantity given **per orem**.

The doses administered by way of the rectum are generally about 25 per cent greater than the doses per orem.

The doses for children and for aged persons also differ materially from the doses for adults in the prime of life.

The following scale of doses for patients of different ages is a sufficiently reliable guide for dispensers:

Ages.	Number of six- teenths of the full adult dose:
1 to 4 months	1
5 to 8 months	1½
9 to 18 months	2
1½ to 3 years	3
4 years	4
5 "	5
6 "	6
7 "	7
8 "	8
10 "	9
12 "	10
13 "	11
15 "	12
18 "	13
20 "	14
25 "	15
30 to 45 years.....	16
50 years	14
60 "	12
80 "	10
100 "	8

The two most common rules for estimating the doses for children are those of Dr. Young and Dr. Cowling. They are as follows:

Dr. Young's Rule: Divide the age of the child (stated in years) by that age + 12, and by the quotient multiply the full ordinary adult dose. The product is the dose to be given to a child of that age.

Ex. The child is 3 years old. Then $\frac{3}{3+12} = \frac{3}{15} = \frac{1}{5}$, and

therefore a child 3 years of age should be given $\frac{1}{5}$ of the adult dose. If the dose for an adult is 10 grains, then the dose for a child 3 years old should be $10 \times \frac{1}{5}$, or 2 grains. If the adult dose is $\frac{1}{2}$ grain, then the dose for a child of 3 years will be $\frac{1}{2} \times \frac{1}{5} = \frac{1}{10}$ grain.

Dr. Cowling's Rule: Add 1 to the age of the child (in years), and divide by 24; then multiply the adult dose by the quotient.

By this rule the dose for a child 3 years old would be $\frac{1}{6}$ of the adult dose, for $\frac{3+1}{24} = \frac{4}{24} = \frac{1}{6}$.

But the foregoing scale and rules do not apply to narcotics, nor to mild cathartics, alteratives and tonics. The doses for children found by the application of these rules should be diminished one-half when the medicine is a powerful narcotic. On the other hand, two or three times the quantity found by these rules may be given of mild cathartics, alteratives and tonics.

EXERCISES.

- 280.—Add together $\frac{1}{3}$, $\frac{2}{3}$, $1\frac{1}{2}$ and $\frac{4}{5}$.
- 281.—Add together $3\frac{1}{4}$, $\frac{3}{4}$ and $\frac{1}{4}$.
- 282.—Subtract $\frac{2}{5}$ from $\frac{3}{4}$.
- 283.—Subtract $\frac{1}{6}$ from $\frac{4}{15}$.
- 284.—Convert 0.1234 into a common fraction.
- 285.—Convert $\frac{3}{4}$ into a decimal fraction.
- 286.—Add together $\frac{3}{4}$ and 1.50.
- 287.—Subtract 0.75 from $\frac{7}{8}$.
- 288.—Multiply $\frac{3}{4}$ by $\frac{3}{4}$.
- 289.—Multiply $\frac{1}{4}$ by $\frac{1}{5}$.
- 290.—Multiply $1\frac{3}{4}$ by $\frac{1}{4}$.
- 291.—Multiply 0.333 by $1\frac{1}{2}$.
- 292.—What is $\frac{1}{30}$ of 2.
- 293.—What is $\frac{1}{30}$ of $\frac{2}{3}$.
- 294.—Multiply $\frac{2}{3}$ by $\frac{1}{30}$.
- 295.—Divide $\frac{2}{3}$ by $\frac{1}{30}$.

296.—Divide. 4 by $\frac{2}{3}$.

297.—How many doses of $\frac{1}{48}$ grain each can be made out of $\frac{3}{4}$ grain of strychnine?

298.—Divide 1.75 by $\frac{7}{8}$.

299.—Divide $\frac{3}{5}$ by 0.250.

300.—Multiply $1\frac{1}{2}$ by 32.

301.—How many grains of morphine sulphate will be required to make three doses of 0.01 Gm each?

302.—If the adult dose be 5 grains, what is about the dose for a child 10 years old?

303.—The adult dose being 30 minims, what is about the dose for a child 4 years old?

304.—The adult dose being 1 fluidrachm, what is about the dose for a patient of 60 years?

305.—The adult dose by mouth being 1 grain, what is about the dose for a hypodermatic injection for a girl of 15 years?

306.—The adult dose by mouth being half an ounce, what is the approximate dose for an enema for a man of 70 years?

307.—The dose for an adult is $\frac{1}{36}$ grain; multiply that by $1\frac{2}{3}$ to find the dose for a child of 15. What is the answer?

308.—How large a quantity of the remedy is required for four doses daily; for a period of ten days, for a youth of 18 years, if the full adult dose is $\frac{1}{64}$ grain?

309.—A mixture measuring four fluidounces, to be taken in teaspoonful doses, contains $\mathfrak{ss}$ of an active remedy. What is the single dose?

310.—A prescription calls for six powders, each to contain $\frac{1}{8}$ grain of an active constituent. What is the whole quantity required of that constituent?

311.—The adult dose being $\frac{1}{200}$ grain, how many doses for a woman 25 years old are contained in $\frac{1}{2}$ grain?

312.—How much of the remedy must be put into an eight-ounce mixture to make each dessertspoonful contain $\frac{1}{4}$ grain?

313.—A prescription calls for $\mathfrak{ss}$ of a salt to be dispensed in a six-ounce mixture of which the dose is to be a tablespoonful. What is the single dose of the salt?

314.—A prescription calls for 10 grains of an active remedy to be divided between 30 pills and the directions are to take 3

pills morning and night. What is the single dose of that remedy?

315.—If the dose be 5 grains, how much must be used to make 12 pills, two to be taken at a time.

316.—A prescription calls for gelatin-coated granules, each to contain 0.001 Gm of strychnine. Having no granules prepared according to the metric system, could you dispense any prepared according to the old system of weights, and, if so, what kind as to dose?

317.—A pill mass is made of equal parts by weight of four ingredients. One drachm of this mass is ordered to be made into twelve pills. How much of each ingredient will be contained in each pill?

318.—A mass is made of $1\frac{1}{2}$ part ferrous sulphate, 2 parts aloes, 3 parts compound cinnamon powder, and 4 parts confection of rose. Of this mass 30 grains is ordered to be made into pills each weighing 5 grains. How much sulphate of iron and how much aloes will be contained in each pill?

319.—How much aconitine is required to make 12 pills containing $\frac{1}{300}$ grain each?

320.—How much medicine will be required for three doses daily for two weeks, each dose being $\frac{1}{64}$ grain?

321.—A prescription calls for doses each containing $\frac{1}{30}$ grain. The prescriber telephones to you in time to reduce the dose one-fourth. What quantity would you use to dispense 24 doses?

322.—A prescription orders an eight-ounce mixture containing $\frac{1}{20}$ grain of mercuric chloride in each dose of one fluidrachm. How much of the mercuric chloride will be required to make six ounces of the mixture?

323.—A medicine contains $\frac{1}{8}$ grain of the active ingredient in each dose. If you reduce the strength to $\frac{2}{3}$ of that, how much of the active substance must you take to make 48 doses?

324.—If you divide 1 milligram into 30 parts, how much will each part weigh?

325.—What is $\frac{1}{4}$ of $\frac{1}{2}$ grain?

326.—Convert 0.0001 Gm into grains.

327.—Convert 15 grains into Gm.

328.—A prescription calls for one dose of each of several ingredients, the quantities of all of which are expressed in grains.

How many Gm of each ingredient will be required for fifteen doses?

329.—How many milligrams in 4 grains?

330.—How many milligrams in 3 grains?

331.—How many grains in 0.5 Gm?

332.—How many grains in 30 milligrams?

333.—How many grains in 400 milligrams?

334.—How many grains in 0.100 Gm?

PART III.

THE MAKING OF SOLUTIONS AND MIXTURES OF ANY GIVEN STRENGTH INCLUDING THE DILUTION, FORTIFICATION AND MIXING OF ALCOHOL.

In computing the proportions of materials required for making solutions and mixtures of any given percentage strength all the quantities employed should refer to one common unit of weight.

Accurate results are more readily obtained when all the materials, ingredients and diluents, as well as products, are measured by weight because mass is not affected by contraction or expansion of volume.

Gravimetric methods are always practicable and exact, and for most purposes in pharmaceutical and chemical computations and laboratory work they are preferable in point of convenience as well as scientific accuracy.

A contraction of volume nearly always results from solution whether the substance dissolved be a solid, a liquid or a gas. In other words, the volume of the resultant solution is nearly always less than the sum of the original volumes of the solvent and the dissolved matter. But the volume of the solution is always greater than that of the solvent alone.

When 49.836 volumes of water and 53.939 volumes of absolute alcohol are mixed the total 103.775 volumes contract to form 100 volumes (at 15°C.).

One liter of absolute acetic acid at 15°C. weighs 1056.2 Gm; but one liter of acetic acid of from 76% to 80% strength by weight weighs 1075.5 Gm. (Acetic acid below 76% and above 80% has a lower specific density.)

When no chemical action accompanies the process of solution there is nevertheless a liberation of heat (a rise of temperature of the liquid) attendant upon a contraction of volume, and an absorption of heat (depression of temperature) attendant upon an expansion of volume.

When a salt containing a large amount of water of crystallization is dissolved in water the volume of the resultant solution may exceed the sum of the original volumes of the salt and the water; but when an anhydrous salt capable of taking up much water of crystallization is dissolved in water a contraction of volume may be expected. Contraction of volume occasionally takes place when a concentrated water-solution of a salt is diluted with more water.

From the foregoing facts it is evident that volumetric expressions of percentage strength and the employment of volume proportions in mixing liquids, do not always and without corrections give accurate results, and that the specific densities of solutions do not always constitute reliable indications of strength.

The strength of solutions and of alcohol should, therefore, always be expressed in per cent. by weight and not in per cent. by volume, nor should they be expressed by specific densities except in cases where circumstances warrant. For pharmaceutical purposes it is nevertheless in some cases so convenient to prepare solutions and liquid mixtures volumetrically, or to measure the solids by weight and the liquids by volume in making preparations composed of both, that it is defensible when the results are sufficiently accurate.

Whenever mixtures or solutions of liquids are made by volume, as when alcohol is diluted with water, or when weaker alcohol is fortified by the addition of stronger alcohol, correction is made for the attendant contraction of volume by setting the mixture aside until contraction ceases and the liquid has resumed the required or standard temperature, after which the requisite final volume of the mixture is made up by adding the additional quantity of water necessary.

The term **ingredient** will here be applied to each of the two components of any mixture or solution.

The components of a solution are the solvent and the dissolved substance. The solvent may be any liquid. The dissolved substance may be any solid or any liquid.

The ingredients of a mixture may be the same as those of a solution, and one or both of the ingredients of a solution or liquid mixture may be composed of two other ingredients.

The ingredients out of which a salt solution is made may be the salt and water, or the salt and a solution, or a solution and water, or two solutions of the same salt but of different strengths.

The materials out of which a mixture of alcohol and water is made may be water and absolute alcohol, or a stronger and a weaker alcohol, or water and a strong alcohol, or a weak alcohol and absolute alcohol.

The ingredients of a standardized powdered opium may be opium and the inert diluent (such as milk sugar), or a stronger and a weaker opium.

In other words the term ingredient is, for the sake of convenience, used to designate any material, solvent, diluent, or constituent of any solution or of any mixture whether solid or liquid.

The **value** of any ingredient (whether valuable or valueless) is its percentage strength. If the ingredients are salt and water, then the value of the salt is 100 and that of the water is 0 or *vice versa*. In a mixture of water and absolute alcohol the water has a value of 0 and the value of the absolute alcohol is 100 or *vice versa*.

If a mixture consists of opium and milk sugar and its value is to be expressed in terms per cent. of opium then the value of the opium is 100 and that of the milk sugar is expressed by 0 or *vice versa*; but if the value of the mixture is to be expressed in per cent. of morphine then the value of the opium in it must also be given in the same terms. Thus if an opium containing 16% of morphine is to be diluted with milk sugar to 14% of morphine, then the value of the opium as an ingredient is 16 and that of the milk sugar 0.

If a mixture is to be made of alcohol and glycerin to contain a definite per cent. of that alcohol by weight, then the value of the alcohol should be stated as 100 and that of the glycerin as

0; but if the value of the mixture is to be expressed in per cent. of the kind of glycerin used, then the glycerin as an ingredient is to be given the value of 100 and the kind of alcohol used becomes 0.

The value or percentage strength of either or both of the ingredients may accordingly be any number from 0 to 100.

The **quantities** of materials and products are understood to be by weight and expressed in the same unit for each, whatever that unit may be. The known quantity of one of the ingredients may be any number of weight units and hence may if desired be expressed by 1 or 100 as well as by any other number.

The final product to be made may be liquid or solid, a solution or a mixture. Its value or percentage strength is, of course, intermediate between 0 and 100.

Solutions and all other liquids should if possible be made perfectly clear. This usually means that they must be filtered through a paper filter which results in a slight loss. It is, therefore, customary and good practice to prepare a slightly larger quantity than that ordered or required. This rule holds good especially in the preparation of small quantities of comparatively dilute solutions ordered by physicians in their prescriptions, as, for instance, solutions of alkaloidal salts, etc. Thus when a fluidounce is ordered it is best to make about 5 or 10 per cent. more than the quantity prescribed. One fluidounce of water weighs at 20°C. about 455 grains; it is, therefore, recommended that 500 grains be prepared for every fluidounce required. To make 500 grains of solution it is evident that 5 grains of the active substance must be used for every 1%. A 1% solution requires 5 grains of the active matter and 495 grains of water; a 2% solution 10 grains of the active substance to 490 grains of water; a 3% solution 15 to 485; a 5% solution 25 to 475; etc. After filtration one fluidounce of the solution may then be dispensed by volume.

We will designate the respective proportions, values and actual quantities of materials and products as follows:

a=quantity or proportion of the material or ingredient having a value higher than that of the product.

b=quantity or proportion of the material or ingredient having a value lower than that of the product.

c=quantity of the product (solution or mixture), or the sum of **a** and **b**.

n=actual quantity or number of weight units called for.

A=value (% strength) of the first ingredient (higher than **C**).

B=value (% strength) of the second ingredient, diluent, or solvent (lower than **C**).

C=value (% strength) of the product (intermediate between **A** and **B**).

d=difference between **B** and **C**.

y=difference between **A** and **C**.

z=difference between **A** and **B**.

It makes no difference which one of the two materials or ingredients is designated as **a** and which is designated as **b** provided the value of **a** be always designated by **A**, that of **b** by **B** and that of **c** as **C**, and that the value of **c** is expressed in the same terms as that of **a**.

As the strength of any solution or mixture is, however, expressed in per cent. of the more important constituent of it, it is most expedient to designate as **a** the ingredient which contains the greatest per cent. of that constituent and as **b**, that which contains the least proportion of it. The strength of a salt solution is expressed according to the per cent. of salt in it, and not according to the per cent. of water it contains: hence it is most natural to designate the salt as **a** and its value (**A**) as 100 and to designate the water as **b** and its value (**B**) as 0. When both of the ingredients as well as the product are solutions or mixtures containing the same substance, then the ingredient having a higher value than **C** should be designated as **a** and that having a lower value than **C** should be designated as **b**.

The following equations are self-evident:

$$1. \ a + b = c. \quad 2. \ a = c - b. \quad 3. \ b = c - a.$$

From these three equations it follows that **a** can be deduced from **b** and **c**, **b** from **a** and **c**, and **c** from **a** and **b**.

Whenever **A** is 100, **B** 0 and **c** 100, then **a** is equal to **C**, or **C=a**.

$$4. \quad \mathbf{a \times A + b \times B = c \times C.}$$

The **proportions** of the materials and product may be found from **A**, **B** and **C** as follows:

$$5. \quad \mathbf{a=d.} \quad 6. \quad \mathbf{b=y.} \quad 7. \quad \mathbf{c=z.}$$

The **actual quantities** of the materials or ingredients may be found from the proportions if the quantity (**n**) of product be known; and if the quantity to be used of one of the materials (**a** or **b**) be known the quantity of the other material and of the product may also be found from **A**, **B** and **C**. Thus, since the **proportions** of **a**, **b** and **c** must be **d** of **a**, **y** of **b**, and **z** of **c**, the following equations may be used:

8. To find the quantities required of **a** and **b** from **A**, **B**, **C** and the known quantity (**n**) of **c**:

$$\mathbf{a = \frac{n \times d}{z}; \quad b = \frac{n \times y}{z}; \quad c = \frac{n \times z}{z}.}$$

9. To find the quantity required of **b** and the quantity of the product (**c**) from the known quantity (**n**) to be used of **a**:

$$\mathbf{a = \frac{n \times d}{d}; \quad b = \frac{n \times y}{d}; \quad c = \frac{n \times z}{d}.}$$

10. To find the quantity required of **a** and the quantity of product (**c**) from the known quantity (**n**) to be used of **b**:

$$\mathbf{a = \frac{n \times d}{y}; \quad b = \frac{n \times y}{y}; \quad c = \frac{n \times z}{y}.}$$

Let it be assumed that we desire to make a sugar solution of 40% strength from sugar and water. Here the sugar has the value (**A**) of 100; the value of the water (**B**) is 0; the value of the product (**C**) is to be 40. Accordingly the **proportional** quantity required of the sugar (**a**) is **d** or 40 (the difference between 0 and 40), the proportional quantity required of water (**b**) is **y** or 60 (the difference between 40 and 100), and the

quantity of product (**c**) would be **z** or 100 (the difference between 100 and 0).

Assuming now that we are to make 500 (**n**) parts or weight units of a 40% solution of sugar out of the required number of parts of each of these materials. Then—

$$a = \frac{500 \times 40}{100} \text{ parts; } b = \frac{500 \times 60}{100} \text{ parts; and } c = \frac{500 \times 100}{500} \text{ parts.}$$

How much 40% solution of sugar can be made out of 200 Gm of sugar, and how much water is required?

The answer is:

$$a = \frac{200 \times 40}{40}; b = \frac{200 \times 60}{40}; c = \frac{200 \times 100}{40}.$$

How much sugar must be added to 300 Gm of water to make a 40% solution, and how much solution will I get?

$$a = \frac{300 \times 40}{60}; b = \frac{300 \times 60}{60}; c = \frac{300 \times 100}{60}.$$

EXAMPLES.

1. How much solution (**c**) can be made of 3 Gm of boric acid (**a**) and 97 Gm of water (**b**)?

$$a + b = c, \text{ or } 3 + 97 = 100.$$

Answer: 100 Gm.

2. How much water (**b**) must be used to make 100 ounces of solution (**c**) out of 3 ounces of boric acid (**a**)?

$$c - a = b, \text{ or } 100 - 3 = 97. \text{ Answer: 97 ounces.}$$

3. How much boric acid (**a**) must be added to 97 grains of water (**b**) to make 100 grains of solution (**c**)?

$$a = c - b. \text{ Answer: 3 grains.}$$

4. What is the % strength (**C**) of a solution of which 100 Gm (**c**) contains 3 Gm of boric acid (**a**)?

As **c** is 100, **A** 100% and **B** 0% it follows that **C=a**. Answer: 3%, or $\frac{3}{100}$.

5. How would you make an 8% solution of boric acid?

Answer: Dissolve 8 parts of boric acid in 92 parts of water.

6. How would you make one ounce of an 8% solution of boric acid?

Answer: Dissolve $\frac{8}{100}$ ounce of boric acid in $\frac{92}{100}$ ounce of water.

7. How would you make 30 Gm of an 8% solution of boric acid?

Answer: Dissolve 2.40 Gm of boric acid [$\frac{8}{100} \times 30$ Gm] in 27.60 Gm [$\frac{92}{100} \times 30$ Gm] of water.

8. How much solution (**c**) of 4% strength (**C**) can be made of 4 grains of cocaine hydrochloride (**a**)?

Answer: 4 grains will make 100 grains of 4% solution [just as 1 grain will make 100 grains of 1% solution; 10 grains will make 100 grains of 10% solution; 8 grains will make 100 grains of 8% solution; 45 grains will make 100 grains of 45% solution; etc.]

9. How much cocaine hydrochloride (**a**) is required to make 100 parts (**c**) of a solution of 4% strength (**C**)?

$$\mathbf{A:C::c:a, \text{ and } a = \frac{4 \times 100}{100}.$$

Answer: 4 parts.

10. What is the % strength (**C**) of a water-solution weighing 100 Gm (**c**) and containing 4 Gm of cocaine hydrochloride (**a**)?

Answer: 4%.

11. If 4 Gm of acetic acid (**a**) of unknown strength when added to 96 Gm of water (**b**) produces a solution containing 4% (**C**) of absolute acetic acid, what was the value or % strength (**A**) of the acetic acid added to the water?

$$\mathbf{a:C::c:A \text{ and } A = \frac{C \times c}{a}}$$

$$4:4::100:100 \text{ and } \frac{4 \times 100}{4} = 100.$$

Answer: 100%.

12. How much silver nitrate (**a**) and water (**b**) must be used to make 30 Gm (**c**) of a solution of 20% strength (**C**)?

The value of the silver nitrate (**A**) is 100%; that of the water (**B**) is 0%; the value of the solution (**C**) is 20%. Hence the proportions of **a**, **b** and **c** must be 20 of **a** and 80 of **b** to make 100 of **c**, or 1 of **a** and 4 of **b** to make 5 of **c** for **a=d**, **b=y** and **c=z**.

The actual quantities are:

$$a = \frac{30 \times d}{100}, \text{ or } \frac{30 \times 20}{100}, \text{ or } 6.$$

$$b = \frac{30 \times y}{100}, \text{ or } \frac{30 \times 80}{100}, \text{ or } 24.$$

$$c = \frac{30 \times z}{100}, \text{ or } \frac{30 \times 100}{100}, \text{ or } 30.$$

The answer then must be: 6 Gm of silver nitrate and 24 Gm of water.

This problem may also be solved as follows:

$$a = \frac{c \times C}{A}, \text{ or } \frac{30 \times 20}{100} = 6.$$

13. How much NaOH (**a**) and water (**b**) must be used to make 500 Gm of a solution (**c**) of 6% strength (**C**)?

A=100; **B**=0; **C**=6. Hence the proportions of **a**, **b** and **c** must be **d** or 6 of **a**, **y** or 94 of **b**, and **z** or 100 of **c**. As **c** is to be 500 we use 5×6 of **a** and 5×94 of **b**.

The problem may also be solved as follows:

$$a = \frac{c \times C}{A}, \text{ and } b = c - a, \text{ or}$$

$$\frac{500 \times 6}{100} = 30 \text{ Gm of NaOH, and}$$

$$500 - 30 \text{ or } 470 \text{ Gm. of water.}$$

14. If 2.25 Gm of salt (**a**) be contained in 50 Gm (**c**) of a

water-solution of it, what is the % strength (**C**) of that solution?

Here **A**=100; **B**=0; and **C** will be found to be 4.50, for

$$c:A::a:C \text{ and } C = \frac{A \times a}{c}$$

$$50:100::2.25:x \text{ and } \frac{100 \times 2.25}{50} = 4.50$$

Answer: 4.50%.

The same answer may be found as follows: The proportions given are 2.25 of **a**, 47.75 of **b** and 50 of **c**. If these numbers be doubled so that **c** will be 100, then **C** will be equal to **a**.

15. If 1000 Gm of water (**b**) be saturated with a salt (**a**) and the total weight of the solution formed be found to be 1100 Gm (**c**) what is the % strength of that solution (**C**)?

As **a**+**b**=**c** it will be seen that **a**=100, **b**=1000, and **c**=1100. If 1100 of **c** contain 100 of **a** then 100 of **c** must contain $\frac{100}{11}$

$$\text{of } a, \text{ for } C = \frac{A \times a}{c}, \text{ or } \frac{100 \times 100}{1100} = 9.0909\%.$$

A=100; **B**=0; **C**=9.0909; and the proportions of **a**, **b** and **c** derived from those values will be found to be **a**=**d**, **b**=**y** and **c**=**z**.

16. I have 24 Gm of iodine (**a**) and I want to make an alcoholic solution of all of it of 8% strength (**C**). How much alcohol (**b**) must I use?

As **A**=100, **B**=0 and **C**=8 it follows that **a** or **d** is 8, **b** or **y** is 92, and **c** or **z** is 100. Hence 8 Gm of iodine will make 100 Gm of the solution and 24 Gm will make 300 Gm.

The problem may also be solved as follows: **C**:**a**::**A**:**c** and

$$c = \frac{a \times A}{C}. \text{ Hence } \frac{24 \times 100}{8} = 300 \text{ (c), and } c - a = b.$$

17. What quantities of 85% acid and 70% acid of the same kind are equivalent to each other?

70 parts of 85% acid must be equivalent to 85 parts of 70% acid for $70 \times 85 = 85 = 70$.

a. How many parts of 70% acid will take the place of 70 parts of 85% acid?

$$70:85::70:x.$$

b. How many parts of 85% acid will take the place of 85 parts of 70% acid?

$$85:70::85:x.$$

c. How many parts of 70% acid will take the place of 100 parts of 85% acid?

$$70:85::100:x.$$

d. How many parts of 85% acid will take the place of 50 parts of 70% acid?

$$85:70::50:x.$$

70 parts of 85% together with 15 parts of water must make 85 parts of 70% acid.

In these examples we can find the proportions of **a**, **b** and **c** from **A**, **B** and **C** as in all other cases.

A=85; **B**=0; **C**=70. Hence the proportions are **d**=70, **y**=15 and **z**=85.

18. How much mercuric chloride (**a**) must be added to 10 kilos of water (**b**) to make a solution of 0.1% strength (**C**)?

d=0.1; **y**=99.9; and **z**=100. Hence 99.9:10,000::0.1:**x**.

$$\text{Answer: } \frac{10,000 \times 0.1}{99.9} = 10.01 \text{ Gm.}$$

19. How much (**a**) solution of 25% strength (**A**) will be required to make 600 Gm (**c**) of a solution of 20% strength (**C**)?

20 Gm of a 25% solution must make 25 Gm of a solution of 20% strength just as 2 five dollar bills make the same sum as 5 two dollar bills.

Here **d**=20, **y**=5 and **z**=25. The proportions of 25% solution and water are, therefore, 4 and 1 to make 5 of 20% solution, and to make 600 Gm will require 480 Gm of **a** and 120 Gm of **b**.

$$\mathbf{A:c::C:a, \text{ and } a = \frac{c \times C}{A}}$$

$$25:600::20:x, \text{ and } x \text{ is } 480.$$

20. How shall I make a 30% solution of salt in water?

$$A=100; B=0; C=30.$$

Therefore $d=30$, $y=70$ and $z=100$. Answer. Use 3 parts of salt and 7 parts of water.

21. How much water must be added to 30 Gm of KOH to make a 30% solution of it?

$$A=100; B=0; C=30.$$

Therefore $a=C$ and $b=70$. Answer: Add 70 parts of water.

22. How much zinc sulphate must be added to 200 Gm of water to produce a solution of 4% strength?

$$A=100; B=0; C=4; d=4; y=96; \text{ and } z=100.$$

$$96:200::4:x.$$

$$\frac{200 \times 4}{96} = 8.333 \text{ Gm.}$$

23. How much solution of 3% strength can be made out of 400 Gm of a solution of 18% strength?

$$A=18; B=0; C=3; d=3; y=15; z=18.$$

$$3:400::18:x$$

$$\frac{400 \times 18}{3} = 2400$$

Answer: 2400 Gm.

24. How much solution of 50% strength must be added to 333.33 Gm of water to produce a solution of 30% strength?

$$A=50; B=0; C=30; d=30; y=20; z=50.$$

$$20:333.33::30:x$$

$$\frac{333.33 \times 30}{20} = 500$$

Answer: 500 Gm.

25. How much zinc chloride must be added to a 20% solution of it to increase the strength of the solution to 25%?

A=100; **B**=20; **C**=25; **d**=5; **y**=75; and **z**=80.

Use 1 part of zinc chloride and 15 parts of the 20% solution.

26. How much borax solution of 5% strength must be added to 800 Gm of a borax solution of 2% strength to produce a solution of 3% strength?

A=5; **B**=2; **C**=3; **d**=1; **y**=2; **z**=3.

2:800::1:x

Answer: 400 Gm.

27. How much glycerin must be added to 864 Gm of alcohol to produce a mixture containing 10% of glycerin?

A (glycerin)=100; **B** (alcohol)=0; **C**=10; **d**=10; **y**=90; and **z**=100.

Answer: 96 Gm.

28. How much glycerin must be added to 864 Gm of alcohol to produce a mixture containing 10% of alcohol?

A (alcohol)=100; **B** (glycerin)=0; **C**=10; **d**=10; **y**=90; **z**=100.

Answer: 7776 Gm.

29. How much opium containing 10% morphine must be added to 420 Gm of opium containing 18% of morphine in order to make a mixture containing 13% of morphine?

A=18; **B**=10; **C**=13; **d**=3; **y**=5; and **z**=8.

Answer: 700 Gm.

30. How shall I mix an 85% alcohol and a 50% alcohol to make a 60% alcohol?

100 parts of alcohol of 60% contains 60 alcohol.

100 parts of alcohol of 85% contains 85 alcohol or 25 more than the 100 parts of 60% alcohol contain.

100 parts of alcohol of 50% contains 50 alcohol or 10 less than the 100 parts of 60% alcohol contain.

The excess of absolute alcohol in 100 parts of 85% alcohol is accordingly 25, and the deficiency in 100 parts of 50% alcohol

is 10. To equalize excess and deficiency the **proportions** of 85% alcohol and 50% alcohol must, therefore, be as 100 to 250 or 10 to 25, or 2 to 5, for $100 \times 250 = 250 \times 100$, $10 \times 25 = 25 \times 10$, and $2 \times 5 = 5 \times 2$. Accordingly we use

2 parts of alcohol of 85% strength and
 5 parts of alcohol of 50% strength to make
 —————
 7 parts of alcohol of 60% strength.

In this problem—

A=85; **B**=50; **C**=60; **d**=10; **y**=25; **z**=35.

The **proportions** then are $2+5=7$.

31. How much water (**b**) must be added to 100 kilos (**a**) of 90% alcohol to reduce it to 60% strength (**C**)?

A=90; **B**=0; **C**=60; **d**=60; **y**=30; and **z**=90.

Answer: 50 kilos.

The amount of 60% alcohol which can be made from 1 kilo of 90% alcohol may be found as follows:

$$\mathbf{C:A::a:c} \text{ and } c = \frac{\mathbf{A} \times \mathbf{a}}{\mathbf{C}}$$

$$\frac{90 \times 1}{60} = 1.50. \text{ The answer, } \mathbf{C}, \text{ is 1.50 kilos.}$$

Then as $c=a+b$ it follows that 0.50 kilo of water must be added to each kilo of 90% alcohol to reduce its strength to 60%.

[We may divide **A** by **C** and subtract 1 from the quotient.]

As 60 weight units of alcohol of 100% strength must equal 100 weight units of alcohol of 60% strength it follows that 90 weight units of alcohol of 100% strength must equal 150 weight units of alcohol of 60% strength. But 100 weight units of alcohol of 90% strength consists of 90 weight units of 100% alcohol and 10 weight units of water. Hence if we add 50 weight units of water to 100 weight units of 90% alcohol we must obtain a product containing 90 weight units of 100% alcohol and $10+50$ weight units of water.

The same problem may be solved from the % of water as follows:

$$60:90::40:x; x=60.$$

x is the number of weight units of water required to be added to 90 weight units of absolute (100%) alcohol to produce 50 weight units of 60% alcohol. But the 90 weight units of 100% alcohol contained in 100 weight units of 90% alcohol are already mixed with 10 weight units of water. We must, therefore, add 50 additional weight units of water.

32. I want to make 6 pounds of 60% alcohol from the required quantity of 91% alcohol. How much 91% alcohol is required?

$$d=60; y=31; z=91.$$

$$91:6::60:x, \text{ and } \frac{6 \times 60}{91} = x.$$

33. How much alcohol of 91% strength must be added to 3000 Gm of alcohol of 41% strength to produce a mixture of 75% strength?

$$A=91; B=41; C=75; d=34; y=16; z=50.$$

$$16:3000::34:x$$

Answer: 6375 Gm.

34. How much alcohol of 41% strength must be added to 6375 Gm of alcohol of 91% strength to reduce it to 75%?

See ex. 33. Answer: 3,000 Gm.

The following rules are deducible from the foregoing. They should not be used, however, unless clearly understood.

Rule I. To find the quantity of water which must be added to 1 part of any solution or alcohol of any given % strength (**A**) to reduce it to any given lower % strength (**C**):

Divide A by C and subtract 1 from the quotient.

Rule II. To find the proportional quantities of any two ingredients of known values (**A** and **B**) which must be used to produce a solution or mixture of any given intermediate value (**C**):

d, or the difference between **B** and **C** expresses the quantity required of **a**; **y** or the difference between **A** and **C** expresses the quantity required of **b**; and **z** or the difference between **A** and **B** expresses the quantity of product obtained (**c**) or the sum of **a** and **b**.

This rule is the same as given in the Pharmacopœia under the head of Diluted Alcohol and Rule II in this book under the head of Alligation, p. 37, and it is based upon the equation:

$$a \times A + b \times B = c \times C$$

Rule III. To find the actual number of parts required of each of any two ingredients of known values (**A** and **B**) to produce a given number of parts (**n**) of solution or mixture of given value (**C**).

$$a = \frac{n \times d}{z}; \quad b = \frac{n \times y}{z}; \quad c = \frac{n \times z}{z}$$

ALCOHOLS AND PROOF SPIRIT.

The commercial alcohol manufactured by the distillers in America usually contains 91 per cent. by weight of absolute ethyl hydroxide— C_2H_5OH . That corresponds to about 94% by volume.

The "Alcohol" of the American pharmacopœias of 1880 and 1890 was also 91% by weight.

But the Alcohol of the pharmacopœia of 1905 (Eighth Decennial Revision) is defined as "a liquid composed of **about** 92.3% by weight, or **about** 94.9% by volume of absolute ethyl alcohol and **about** 7.7% of water." It is described as having a specific gravity of **about** 0.816 at 60°F., or 0.809 at 25°C. (77°F.).

The "Absolute Alcohol" of the Pharmacopœia is required to contain not less than 99% of ethyl hydroxide or not more than 1% of water.

The "Diluted Alcohol" of the American Pharmacopœia (VIII.) is defined as "a liquid composed of **about** 41.5% by weight or **about** 48.9% by volume" of ethyl hydroxide; it is described as having a specific gravity of **about** 0.936 at 60°F., and **about** 0.930 at 25°C. (77°F.)."

"Proof Spirit" is defined by Section 3249 of the Revised Statutes of the United States as a spirit containing one-half its volume of alcohol of the specific gravity of 0.7939 at 60°F. The statute does not state the temperature of the water referred to as the unit of expression, but the "Gauger's Manual" published by the Internal Revenue Service states that the standard is water at its maximum density, or at 4°C. Absolute alcohol according to E. R. Squibb has the sp. gr. 0.7938 at 60°F, referring to water at the same temperature, but according to A. B. Lyons its sp. gr. is 0.7935. It is evident, however, that the intent of Section 3249 of the Revised Statutes of the United States is that proof spirit shall be a spirituous liquid containing 50 per cent. by volume of absolute alcohol.

The strength of alcoholic liquids is for purposes of taxation expressed in "degrees proof," or per cent. proof. Proof spirit is 100 degrees or per cent. proof; water is 0° and absolute alcohol is 200° proof. The standard spirit hydrometers of the Internal Revenue Service indicate 100 for proof spirit at 60°F. When at that temperature the hydrometer indicates less than 100 "per cent. proof" the spirit is said to be "below proof"; when it indicates a higher per cent. proof the spirit is "above proof." Thus the scale of the government's standard hydrometer is so divided that the per cent. proof as defined by the law is shown instead of the per cent. of absolute alcohol. Hence each space or degree on that scale corresponds to 0.5 per cent. by volume of absolute alcohol.

A proof gallon of spirit for purposes of taxation is any quantity of spirit containing one-half gallon of absolute alcohol. A proof gallon of spirit which is less than 50% strength by volume measures more than a liquid gallon or "wine gallon"; but if the spirit is above proof then one wine gallon of it is more than a proof gallon.

The commercial alcohol of 94% strength by volume is 188° proof or 88° above proof. The official alcohol of 94.9% strength by volume is 189.8 degrees proof or 89.8 degrees above proof.

100 wine gallons of commercial alcohol (91% strength by weight or 94% by volume) is equal to 188 wine gallons of proof spirit or 188 proof gallons.

PART IV.

MISCELLANEOUS EXAMPLES IN PROPORTION AND PERCENTAGE (INCLUDING EXAMPLES SOLVED BY ALLIGATION.)

335.—If the price of muslin be 4 cents a yard, what is the price per meter?

336.—The price per meter being 10 cents, what is the price per yard?

337.—The price per liter being \$1.30, what is the price per gallon?

338.—If 3 gallons cost \$2.80, what is the price per liter?

339.—If the price per liter be \$2.11, what is the price per wine-pint?

340.—What is the cost per kilogram, at \$2.20 per pound?

341.—At 36 cents per ounce, what is the price per kilogram?

342.—At \$1.00 per kilogram, what is the price per avoirdupois-ounce?

343.—At \$1.00 per kilogram, what is the price per avoirdupois-pound?

344.—At \$1.00 per kilogram, how many avoirdupois-pounds will \$10.00 buy?

345.—At \$2.50 per Gm, what is the price per grain?

346.—At 6 cents per grain, what is the price per Gm?

347.—At 65 cents per Gm, what is the price per grain?

348.—A Solution of Chloride of Iron is required to contain 63 per cent. crystallized ferrie chloride. How many avoirdupois-ounces of that solution can be made from $\frac{1}{4}$ pound solid ferrie chloride, and how much water will be required?

349.—How many ounces, 5 per cent. solution, can be made of 1 pound of borax?

350.—How many Gm of a mixture of resin of podophyllum and milk sugar, containing 20 per cent. of the active remedy, can be made of one ounce of the resin?

351.—I have an avoirdupois-ounce of opium containing 10 per cent. of morphine, and I want to mix it with enough milk sugar to produce a mixture containing 1 per cent. of morphine. How many Gm of such a mixture can be made from the whole ounce of opium, and how much milk sugar is required?

352.—How many Gm of 12 per cent. solution can be made of one kilogram of granulated zinc chloride?

353.—How many ounces of a 6 per cent. solution of carbolic acid in olive oil can be made of one pound of the phenol?

354.—How many pounds diluted acetic acid (6%) can be made of one pound absolute acetic acid?

355.—How many ounces of phenol must be added to one pound of glycerin to produce a 50 per cent. solution?

356.—How many ounces of extract of belladonna must be used with one pound of benzoinated lard to produce an ointment of belladonna containing 10% of the extract?

357.—How many ounces of oil of peppermint must be added to one pound of alcohol to make a 12 per cent. solution?

358.—How many grains cocaine hydrochloride must be added to 455.38 grains of water to produce a 3 per cent. solution?

359.—What quantities of tannin and benzoinated lard are required to make one ounce of a 10 per cent. ointment?

360.—What quantities of sulphur and benzoinated lard are required for one pound of a 30 per cent. ointment?

361.—What quantities of oil of orange peel and alcohol are required to make one pound of spirit of orange of 6 per cent. strength?

362.—How much boric acid and powdered talcum must be used to make one pound of a powder containing 3 per cent. of the acid?

363.—Compound jalap powder contains 35 per cent. jalap and 65 per cent. cream of tartar. How much of each will be required to make 4 ounces?

364.—Dover's Powder contains 10 per cent. of each of opium and ipecac, and the remainder is milk sugar. How much of each ingredient is required to make one pound?

365.—I want 120 Gm of a 4 per cent. solution of sodium thiosulphate in water. How much of each must I use?

366.—One kilogram of a solution leaves, on evaporation, a residue of 125 Gm of potassium bromide. What was the per cent. strength of the solution?

367.—What is the per cent. strength of a solution containing $2\frac{1}{2}$ ounces in 32 ounces?

368.—If one pound of jalap yield one ounce of resin, what is the per cent. of resin in the drug?

369.—If 5 Gm of opium yield 666 milligrams of morphine, what is the morphine strength of that opium expressed in per cent.?

370.—If 25 pounds of a certain drug gives $\frac{3}{4}$ lb of solid extract, what is the yield expressed in per cent.?

371.—If it takes $3\frac{1}{8}$ lb of drug to make 11 ounces of its extract, what is the percentage yield?

372.—If 5 Gm of cinchona bark gives 275 milligrams of total alkaloids, what percentage does that show?

373.—What percentage strength corresponds to "1 ounce to the pound"?

374.—If 573 Gm contain 28.65 Gm of active constituent, what is the percentage strength?

375.—If I dissolve 5 Gm of cocaine hydrochloride in 100 Gm of water, what is the percentage strength of the resulting solution?

376.—What is the percentage strength of a mixture consisting of 6 lb of diluent and $\frac{1}{4}$ lb of active constituent?

377.—What is the percentage strength of a solution of 20 parts of salt in 100 parts of water?

378.—What is the percentage strength of a solution of 25 parts of salt in 100 parts of alcohol?

379.—I pour some tar into one pound of alcohol, and find the combined weight of the two together to be 19 ounces; I then allow the tar to be dissolved, aiding the solution by shaking; what is the per cent. strength of the tar solution?

380.—What proportions of cocaine hydrochloride and water are required to make one ounce of a 4 per cent. solution?

381.—What proportions of zinc sulphate and water are necessary to make 8 ounces of a 10 per cent. solution?

382.—How much of a 20 per cent. solution of sodium carbonate can be made of 20 Gm of the salt?

383.—What amount of water must be added to 4 ounces of potassium iodide to make a 50 per cent. solution?

384.—What will be the percentage strength of a solution consisting of 25 Gm potassium iodide and 100 Gm water?

385.—If 1,000 grains of solution contain 400 grains of salt, what is the percentage strength of the solution?

386.—If 1,000 grains of salt solution contain 400 grains of water, what is the percentage strength of the solution?

387.—A certain root yields about 16 per cent. solid extract to alcohol; how much extractive should be left upon evaporating 50 ml of the fluidextract?

388.—Socotrine aloes gives 22 per cent. waterextract; how much of the extract is obtained from 9 ounces of aloes?

389.—How much ergot is required to make 100 Gm of extract if the yield be 20%?

390.—How much tincture of 10% strength is equivalent to 15 ml of fluidextract?

391.—A certain leaf yields about 22 per cent. extractive to a 66 per cent. alcohol; how much solid extract is contained in 1 ounce of a 10 per cent. tincture made with that menstruum out of that drug?

392.—Indian cannabis yields 13 per cent. alcoholic extractive; how much of the fluidextract would be equivalent to 1 grain of the solid extract on that basis?

393.—If the average yield of extract from colocynth pulp be 33 per cent., and colocynth consists of 75 per cent. seed and 25 per cent. pulp, how much drug is required to make one pound compound extract of colocynth containing 16 per cent. of the simple extract?

394.—If digitalis yield 25 per cent. extractive to diluted alcohol, how much extractive is contained in a tincture of 10 per cent. strength?

395.—Tincture of digitalis is 6.6 times the strength of the infusion, and the extract is 50 times the strength of the tincture; how much tincture, infusion, fluidextract, and extract, respectively, must be taken to represent 66 grains of the crude drug?

396.—How much extract ought to be obtained on evaporating 800 ml of the fluidextract of any drug yielding $\frac{1}{8}$ of its weight of extractive?

397.—A certain drug yields 22 per cent. extractive to the official menstruum for its fluidextract; how much solid extract should remain upon evaporation of 40 ml of the fluidextract?

398.—If opium yield 60 per cent. extractive to diluted alcohol, what would be the amount of extractive in 60 grains of a 10% tincture?

399.—If a moist opium containing 10 per cent. morphine be dried, and is found to lose 20 per cent. of moisture in drying, what will be the percentage of morphine in the dried opium?

400.—If the yield of solid extract from a given drug be 9 per cent., how much of the drug will be required to make 100 ounces of the extract?

401.—If the yield of resin of podophyllum be 4.50 per cent., how much drug will be required to make one pound of the resin?

402.—How much morphine is contained: **a)** in one ounce of a 10% tincture of opium made from powdered opium containing $13\frac{1}{2}$ per cent. morphine? **b)** in 1 Gm tincture made from an opium containing 12 per cent. morphine?

403.—Physostigma yields 3 per cent. extractive to the official alcohol, but 12 per cent. to a much weaker alcoholic menstruum; if the dose of the former extract be $\frac{1}{10}$ grain, what is the dose of the other, assuming that both menstrua will extract the whole of the active constituents?

404.—State the amount of solid extract yielded by 1 pound tincture of physostigma of 10% strength on the assumption that the crude drug yields 3 per cent. alcoholic extractive.

405.—How much fluidextract of podophyllum will be about equivalent to 1 Gm of the resin if the drug yields 4.5% of resin?

406.—If we mix $\frac{1}{2}$ pound of opium containing $17\frac{1}{2}$ % of morphine, one pound containing $12\frac{1}{2}$ %, and 6 ounces containing 15%, what will be the % of morphine of the whole mixture?

407.—If we mix 2 pounds of powdered cinchona containing 8% of total alkaloids with 3 pounds containing 4%, what will be the % of alkaloids of the mixture?

408.—If one pound of a solution of 1.200 specific density be

mixed with one pound of water, what will be the specific weight of the mixture?

409.—If a salt solution of 10 per cent. strength be mixed with an equal weight of another solution of the same salt, but of 20 per cent. strength, what will be the strength of the mixture?

410.—How much water must be added to a solution of the specific weight 1.400, to reduce the specific density to 1.200?

411.—How much official water of ammonia containing 10 per cent. of the gas H_3N , can be made from 10 pounds of the official "stronger water of ammonia" which contains 28 per cent. of H_3N ?

412.—How much official diluted acetic acid (6%) can be made from the official "glacial acetic acid" (100%)?

413.—How much water must be added to one pound official acetic acid (36%), to reduce it to a 4 per cent. acid?

414.—How much official glacial acetic acid is required to make 2 pounds of the official diluted acetic acid?

415.—How much official "stronger water of ammonia" (28%) is required to make 10 pounds of a 10 per cent. solution of ammonia?

416.—How much diluent must be added to a 70 per cent. solution, to reduce it to a 30 per cent. solution?

417.—How much water must be added to the official solution of ferric sulphate (36%) to reduce its strength so that it contains 10 per cent. of the salt?

418.—What quantities of water and of official solution of chloride of iron (48.3%) are required to make one pound of a 10 per cent. solution of ferric chloride?

419.—How much "potassa" containing 90 per cent. of potassium hydroxide will be required to make 5 pounds of a solution containing 50 per cent. of the hydroxide?

420.—We have ingredients of 10 per cent., 13 per cent., and 20 per cent. strength, respectively. We want a mixture of 15 per cent. What proportions must be used?

421.—We have 10 pounds of 20 per cent. strength and any quantity that may be required of 10 per cent., and 13 per cent., respectively. Wishing to use the whole 10 pounds of 20 per

cent. strength to make a mixture of 15 per cent., how much must be used of each of the other two?

422.—We have ingredients of 10 per cent., 13 per cent., and 20 per cent., respectively. We want 20 pounds of a mixture containing 15 per cent. What quantities shall we use of each of the three ingredients?

423.—If we have a sufficient supply of diluted acetic acid (6%) and glacial acetic acid (100%) what proportions of these two must be mixed to produce the official "acetic acid" (36%)?

424.—How much sugar of milk must be used as a diluent to reduce an opium of 16 per cent. strength, to a mixture containing $12\frac{1}{2}$ per cent. morphine?

425.—Having three lots of jalap containing, respectively, 16 per cent., 13 per cent., and 9 per cent., and wishing to produce a mixture containing $12\frac{1}{2}$ per cent., what proportions must be used?

426.—Having five lots of scammony containing, respectively, 78, 82, 88, 89, and 91 per cent. of resin, in what proportions must they be combined to produce a mixture of 80 per cent.?

427.—In making tincture of a certain drug, by percolation, I find that the total percolate obtained by exhausting the drug, assays 2.75 per cent. solid extract. How much alcohol must be added to reduce it to 2 per cent.?

428.—How much jalap of 10 per cent. must be mixed with jalap of 16 per cent. to make one pound of jalap of 12 per cent.?

429.—Having two lots of powdered cinchona of 2 per cent. and 7 per cent., respectively, how shall I mix them to make one pound of a mixture of 5 per cent.?

430.—How much water must be added to reduce a 60 per cent. solution of chloride of iron to the official standard strength (48.3%)?

431.—How much water must be added to a water solution of 1.350 sp. dens., to reduce it to 1.26 sp. density?

432.—Resin cerate of the U. S. P. VIII is composed of 35 parts of resin, 15 parts of yellow wax and 50 parts of lard; what quantities are required to make one pound?

433.—What quantities of the ingredients are required to

make five pounds of a cerate composed of 30 parts of wax, 20 parts of petrolatum and 50 parts of lard?

434.—What is the weight of a mixture of 80 ml of glycerin of the specific density 1.250, 80 ml of water and 160 ml of alcohol of the specific density 0.820?

435.—What is the % strength of a tincture made from 300 Gm of a powdered root the percolation being continued until 1000 ml of percolate has been collected and the menstruum being alcohol of the specific density 0.85?

436.—Seidlitz powder is composed of 8 parts of sodium bicarbonate, 24 parts of Rochelle salt, and 7 parts of tartaric acid. It weighs 195 grains. How much of each ingredient will be required to make 15 such powders?

437.—Dover's powder is composed of 10% ipecac, 10% opium and 80% milk sugar. Write a formula for 4 medicinal ounces.

438.—The adhesive plaster of 1880 was made of 7 parts of resin, 3 parts of wax and 40 parts of lead plaster. Write a formula for one pound.

439.—What is the % strength of a solution made by dissolving 70 Gm of iodine in enough alcohol of 0.812 sp. density to obtain one liter?

440.—What is the weight in commercial ounces of one gallon of ammonia water the specific density of which is 0.900?

441.—Write a formula in parts by weight for 100 parts of a plaster composed of 8 parts of wax and 72 parts of Burgundy pitch.

442.—Write a formula in parts by weight for the quantity of mass required to make 12 pills each to contain 2 grains each of aloes and soap.

443.—How much alum and water must be used to make 250 Gm of a 5% solution?

444.—How much cocaine hydrochloride and water must be used to make 30 Gm of a 5% solution?

445.—What is the % strength of a solution weighing 8 avoirdupois-ounces and containing $\frac{1}{2}$ ounce of potassium chlorate?

446.—How much sodium carbonate is required to make one pound of a 25% solution?

447.—The dry residue obtained by evaporating 900 Gm of a

solution of ammonium chloride is found to be 81 Gm. What was the % strength of that solution?

448.—How much 7.5% solution can be made of 1 ounce of salt?

449.—What quantities of 36% acid and 45% acid of the same kind are equivalent to each other in saturating value?

450.—What quantity of 27% solution is equal to 400 Gm of a 30% solution?

451.—How much salt must be added to 500 Gm of a 3% solution to increase its strength to 4%?

452.—How much phenol must be dissolved in one liter of water to make a solution of 0.5% strength?

453.—How much water must be added to 16 ounces of a 10% solution to reduce it to 8% strength?

454.—How much acid of 60% strength must be added to 2 pounds of acid of 43% strength to change its strength to 48%?

455.—How much proof spirit must be added to 1 gallon of 94% alcohol (by volume) to reduce the strength to 85% by volume, and what must be done to make proper correction for the contraction of volume which takes place?

456.—How much alcohol of 60% by volume can be made of 1 pint of alcohol of 94% by volume by dilution with water?

457.—How much alcohol of 60% strength by weight can be made of an alcohol of 91% strength by weight by dilution with water?

458.—How much water must be added to 4 lb of alcohol of 91 per cent. strength to reduce it to 66 per cent.?

459.—How much water must be added to 10 lb of 84 per cent. alcohol to reduce it to 50 per cent.?

460.—How much water must be added to 8 lb of 80 per cent. alcohol to reduce it to 45.5 per cent.?

461.—How much water must be added to the official alcohol to reduce it to 60 per cent.?

462.—How much water must be added to 10 lb of 90 per cent. alcohol to make the official diluted alcohol out of it?

463.—How would you produce official diluted alcohol out of 8 lb alcohol of 84 per cent. strength?

464.—How would you reduce 50 lb of alcohol of 78 per cent. strength to 60 per cent.?

465.—How shall 1 lb of alcohol of 68 per cent. strength be reduced to 47 per cent.?

466.—How would you reduce 1 kilogram of alcohol of 88 per cent. strength to 70 per cent.?

467.—How would you make 10 lb of alcohol of 60 per cent. strength out of 91 per cent. alcohol and water?

468.—How would you make 8 lb of 45.5 per cent. alcohol out of 85 per cent. alcohol?

469.—How much 90 per cent. alcohol is necessary to make 2 kilograms of 80 per cent. alcohol?

470.—How much 70 per cent. alcohol is required to make 10 lb of 40 per cent. alcohol?

471.—In what proportions must 91 per cent. alcohol and 30 per cent. alcohol be mixed to produce a mixture of 50 per cent. strength?

472.—We have several lots of alcohol of 88%, 85%, 76%, and 68%, respectively; in what proportions must they be mixed to produce a mixture of 84% strength?

473.—How shall I make 5 kilograms of 75 per cent. alcohol out of 91 per cent. alcohol and 34 per cent. alcohol?

474.—How much water must be added to 10 lb of alcohol of 90 per cent. strength to produce an alcohol of 86 per cent.?

475.—How much 91 per cent. alcohol must be added to 10 lb of water to produce an alcohol of 88 per cent. strength?

476.—How much alcohol of 91 per cent. strength must be added to 25 kilograms of alcohol of 48 per cent. strength to produce a mixture of 67 per cent. strength?

477.—How much alcohol of 84 per cent. strength must be added to 10 lb of alcohol of 42 per cent. strength to produce a mixture having 45.5 per cent. strength?

478.—State the percentage alcoholic strength of a mixture of 1 part 60 per cent. alcohol and 2 parts water.

479.—State the percentage alcoholic strength of a mixture of 2 parts official alcohol and 1 part water.

480.—How much alcohol of 40 per cent. strength can be made from 1,000 Gm of alcohol of 80 per cent. strength?

481.—How many parts alcohol of 80 per cent. strength can be made from 80 parts alcohol of 91 per cent. strength?

482.—How much water is required to dilute an alcohol of 50 per cent. strength, to one of 45.5 per cent.?

483.—How many parts of alcohol of 45.5 per cent. strength can be made from 45.5 parts of alcohol of 91 per cent. strength?

484.—What proportions of official alcohol and official diluted alcohol must be used to produce an alcohol of 85 per cent. strength?

485.—How much official alcohol must be added to 10 pounds of water to produce a mixture containing 50 per cent. absolute alcohol?

486.—How much alcohol of 91 per cent. strength must be added to 100 parts of alcohol of 60 per cent. strength, in order to produce a mixture of 80 per cent. strength?

487.—How much alcohol of 91 per cent. strength is required to make one pound of alcohol of 66 per cent. strength?

PART V.

TEMPERATURE AND PRESSURE.

CHAPTER I.

THERMOMETRIC SCALES.

The freezing point on the Centigrade thermometer is at 0, and the boiling point at 100.

The freezing point on Fahrenheit's thermometer is at $+32$, and the boiling point at $+212$.

On Reaumur's thermometer the freezing point is at 0, and the boiling point at 80.

"Absolute temperature" is the temperature counted upward from **absolute zero** (which is equal to -273°C). It is expressed in degrees each of which has the same value as each degree of the Centigrade scale. Hence 0°C . is equal to 273° absolute temperature, and 100°C . is equal to 373° absolute temperature. See Chapter II, page 109, for explanation.

Rules for Converting:—

1. To reduce Centigrade degrees to those of Fahrenheit:—**Multiply by 9 and divide by 5; then add 32.**

2. To reduce Fahrenheit's degrees to those of Centigrade:—**Subtract 32, multiply the remainder by 5, and divide the product by 9.**

3. To reduce Reaumur's degrees to those of Fahrenheit:—**Multiply by 9, divide by 4, and add 32.**

4. To reduce Fahrenheit degrees to those of Reaumur:—**Subtract 32, multiply by 4, and divide by 9.**

5. To reduce Reaumur's degrees to Centigrade:—**Multiply by 5, and divide by 4. Or multiply by 1.25.**

6. To reduce Centigrade degrees to Reaumur's:—**Multiply by 4, and divide by 5. Or multiply by 0.8.**

7. To reduce positive Centigrade degrees to Absolute Temperature:—**Add 273.** (See page 109.)

8. To reduce negative Centigrade degrees to Absolute Temperature:—**Deduct the Centigrade degrees from 273.** (See page 109.)

9. To reduce Fahrenheit and Reaumur degrees to Absolute Temperature:—**First reduce to Centigrade; then follow rule 7 or 8.**

EXAMPLES

488.—Reduce— 40°C. to F.

489.—Reduce+ 40°C. to F.

490.—Reduce+ 104°F. to C.

491.—Reduce+ 10°C. to F.

492.—Reduce+ 80°C. to F.

493.—Reduce+ 95°F. to C.

494.—Reduce+ 120°C. to F.

495.—Reduce+ 120°F. to C.

496.—Reduce+ 194°F. to C.

497.—Reduce+ 32°C. to F.

498.—Reduce+ 77°F. to C.

499.—Reduce+ 68°F. to C.

500.—Reduce+ 60°R. to F.

501.—Reduce+ 60°F. to R.

502.—Reduce+ 60°C. to R.

503.—Reduce+ 10°R. to C.

504.—Reduce+ 15°C. to R.

505.—Reduce+ 300°C. to F.

506.—Reduce+ 140°F. to C.

507.—Reduce+ 70°C. to F.

508.—Reduce+ 17°C. to F.

509.—Reduce+ 15°C. to F.

510.—Reduce+ 15°F. to C.

511.—Reduce+ 600°F. to C.

512.—Reduce+ 20°F. to C.

513.—Reduce+ 180°F. to C.

514.—Reduce+ 10°F. to C.

- 515.—Reduce+ 20°C. to F.
- 516.—Reduce+ 4°C. to F.
- 517.—Reduce+ 32°F. to C.
- 518.—Reduce+ 15°C. to Absolute Temperature.
- 519.—Reduce+ 20°C. to Absolute Temperature.
- 520.—Reduce+ 4°C. to Absolute Temperature.
- 521.—Reduce— 10°C. to Absolute Temperature.

CHAPTER II.

CHANGES OF VOLUME OF GASES AND VAPORS UNDER CHANGES OF TEMPERATURE AND PRESSURE.

The vapor density of hydrogen at 0° C., bar. 760 mm, is 1; that of oxygen is 15.88; that of nitrogen is 14.01; that of carbon dioxide is 26.945.

At temperatures above 100° C. the vapor density of water is 8.98 times that of hydrogen at the same temperature and pressure.

1 cubic-decimeter of pure hydrogen at 0° C., bar. 760 mm, weighs about 0.09 Gm.

1 Gm of hydrogen at 0° C., bar. 760 mm, occupies about 11.16 cubic-decimeters.

1 cubic-decimeter of pure oxygen at 0° C., bar. 760 mm, weighs about 1.43 Gm.

1 Gm of oxygen at 0° C., bar. 760 mm, measures about 699 Cc.

1 cubic-decimeter of **dry air**, free from CO_2 , at 0° C., bar. 760 mm, weighs 1.29303 Gm. **Ordinary air** weighs less.

At 0° C. ordinary air weighs 0.00075 less than dry air.

The weight of one cubic-decimeter of ordinary air at 0° C. is $1.29303 \text{ Gm} \times 0.99925$.

At 62° F. ordinary air weighs 0.005 (one-half per cent.) less than dry air.

At 16.67° C. (62° F.) one cubic-decimeter of dry air weighs 1.21858 Gm; the same volume of ordinary air weighs $1.21858 \text{ Gm} \times 0.995$.

1 cubic-decimeter of pure nitrogen at 0° C., bar. 760 mm, weighs about 1.26 Gm.

1 cubic-decimeter of chlorine at 0° C., bar. 760 mm, weighs about 3.17 Gm.

Effects of Variations of Temperature.

The co-efficient of expansion of gases under change of temperature is $\frac{1}{273}$ (or 0.0036650) for each degree at 0° C. For each degree F. the co-efficient of expansion is $\frac{1}{491}$ (or 0.002037) at 32° F. This means that the volume of a gas is increased by $\frac{1}{273}$, or 0.0036650, when the temperature is raised one degree by the Centigrade thermometer, and that its volume is diminished by $\frac{1}{273}$, or 0.0036650, when the temperature is decreased one degree by the Centigrade thermometer; or that 273 volumes of any gas at 0° C. will occupy 274 volumes at 1° C., and 275 volumes at 2° C.; or will occupy 272 volumes at -1° C., or 271 volumes at -2° C.

In the same manner, the volume of a gas at 32° F. is increased by $\frac{1}{491}$ (or 0.002037) when its temperature is raised one degree by Fahrenheit's thermometer, and its volume diminished by $\frac{1}{491}$ (or 0.002037) for each degree F. of increase in temperature, so that 491 volumes at 32° F. will become 492 volumes at 33°, and 501 volumes at 42°, and will occupy only 490 volumes at 31°, and 480 volumes at 22° F.

Hence, knowing the volume of any mass of a gas at any given temperature, its volume at any other temperature may be calculated by the co-efficient of expansion.

Let the temperature be expressed in absolute degrees. Then use the following:

Rule.—Multiply the known volume of the gas by the new temperature, and divide the product by the old temperature.

As zero by the Centigrade thermometer represents 273° absolute temperature, any number of degrees below zero must be deducted from 273 to obtain the absolute temperature; and any number of degrees C. above zero must be added to 273 to obtain the absolute temperature. (See Chapter I.) Hence, if we designate as **a** the known volume of the gas, as **b** the absolute temperature at which it has that volume, as **c** the new absolute temperature at which its volume is sought to be ascertained, and as **x** the volume at the new absolute temperature, or, in other words, the volume sought, then:

$$\frac{a \times c}{b} = x.$$

Examples:

I.—A gas occupies 100 Ce. at 0° C.; what volume will it occupy at 10° C.?

II.—A gas occupies 100 Ce. at 10° C.; what volume will it occupy at 20° C.?

III.—A gas occupies 100 Ce. at -10° C.; what volume will it occupy at 0° C.?

IV.—A gas occupies 100 Ce. at 0° C.; how many Ce. will it occupy at -10° C.?

V.—A gas occupies 100 Ce. at -10° C.; how many Ce. will it occupy at -20° C.?

VI.—A gas occupies 100 Ce. at $+10^{\circ}$ C.; how many Ce. will it occupy at -10° C.?

VII.—A gas occupies 100 Ce. at -10° C.; how many Ce. will it occupy at $+10^{\circ}$ C.?

Solutions:

$$\text{I.}—\frac{100 \times 283}{273} = \frac{28,300}{273} = 103.66+.$$

$$\text{II.}—\frac{100 \times 293}{283} = \frac{29,300}{283} = 103.61+.$$

$$\text{III.}—\frac{100 \times 273}{263} = \frac{27,300}{263} = 103.80+.$$

$$\text{IV.}—\frac{100 \times 263}{273} = \frac{26,300}{273} = 96.33+.$$

$$\text{V.}—\frac{100 \times 253}{263} = \frac{25,300}{263} = 96.19+.$$

$$\text{VI.}—\frac{100 \times 263}{283} = \frac{26,300}{283} = 92.93+.$$

$$\text{VII.}—\frac{100 \times 283}{263} = \frac{28,300}{263} = 107.60+.$$

[When the temperatures are given in degrees of the Fahrenheit scale, they may be transposed, first to Centigrade degrees and then to absolute temperature, after which the same rule is applied as given in the foregoing.]

Effects of Changes of Pressure.

According to the law of Boyle the volume of any gas varies inversely with the pressure to which it is subjected, provided the temperature remains constant; or, which is the same, the density of a gas varies directly as the pressure.

The pressure of "one atmosphere" is equal to that of a column of 760 mm, or 30 inches of mercury. It is about "15 pounds to the square inch."

A gas under a pressure of two atmospheres, measures one-half as much in volume as when under the pressure of one atmosphere, and 100 volumes of gas under the pressure of two atmospheres will become 200 volumes under the pressure of one atmosphere. Hence, knowing the volume of a given mass of any gas at a given pressure, we may compute its volume under any other pressure, by this

Rule.—Multiply the known volume by the known pressure, and divide by the pressure at which the volume is sought to be ascertained. Thus:

If a gas measures 10 volumes at 760 mm pressure, it will measure 10.13+ volumes at 750 mm pressure; because,

$$\frac{10 \times 760}{750} = 10.13+.$$

Effects of Changes of Both Temperature and Pressure.

When both temperature and pressure are changed, the resulting change of the volume is found as follows:

The known volume is multiplied by the pressure under which a gas occupies that volume, and also by the new (absolute) temperature at which the changed volume is to be ascertained; this product is then divided by the new pressure multiplied by the old (absolute) temperature at which the gas occupied its original volume under the pressure stated.

Example:

If a gas occupies 100 Ce. under 760 mm pressure at a tem-

perature of 0° C., we will find the volume it occupies under the pressure of 800 mm at a temperature of 10° C. as follows:

$$\frac{100 \times 760 \times 283}{800 \times 273} = 98.47 +.$$

The rules already given may be represented more conveniently by the following formulas, in which

V=the old volume.

v=the new volume.

T=the old absolute temperature.

t=the new absolute temperature.

P=The old pressure.

p=the new pressure.

Rule I.—To find the change of volume resulting from changed pressure:

$$\frac{V \times P}{p} = v.$$

Rule II.—To find the change of volume resulting from change of temperature:

$$\frac{V \times t}{T} = v.$$

RULE III.—To find the change of volume resulting from change of both temperature and pressure:

$$\frac{V \times P \times t}{p \times T} = v.$$

EXAMPLES.

522.—If a gas occupies 275 volumes at 2° C., how many volumes will it occupy at 0° C.?

523.—If a given mass of gas occupies 80 Cc. at 15° C., how many Cc. will it occupy at 50° C.?

524.—If a given mass of gas occupies 10 Cc. at 0° C., how many Cc. will it occupy at 212° F.?

525.—If a gas occupies one volume at 100° C., how many volumes will it occupy at -10° C.?

526.—If a given mass of gas occupies 50 volumes under 760 mm pressure, how many volumes will it occupy under 756 mm pressure?

527.—If a given mass of gas occupies 120 Cc. under 760 mm pressure, how many Cc. will it occupy under 900 mm pressure.

528.—If a mass of gas measuring one liter, under a pressure of 15 pounds to the sq. in., be subjected to a pressure of 30 pounds to the sq. in., what volume will it occupy?

529.—If a given mass of gas at 15° C. measures one liter under 760 mm pressure, how much will it measure at 10° C. under 1,000 mm pressure?

530.—One liter of oxygen at 0° C. and under 760 mm pressure weighs 1.43 Gm. What is the weight of 2 liters of oxygen at 16° C. under 750 mm pressure.

531.—One liter of hydrogen at 0° C. and under 760 mm pressure weighs 0.08958 Gm. What is the weight of 5 liters of hydrogen at -20° C. under 800 mm pressure?

532.—One liter of nitrogen at 0° C. under 760 mm pressure weighs 1.26 Gm. What will be the volume of 5 Gm of nitrogen at -10° C. under 758 mm pressure?

533.—One liter of air at 0° C. under 760 mm pressure weighs 1.29303 Gm. What is the volume of one pound of air at 10° C. under the pressure of three atmospheres?

534.—One liter of carbon dioxide at 0° C. under a pressure of one atmosphere weighs 1.9657 Gm. What is the volume of 10 kilograms of CO_2 at 8° C. under a pressure of four atmospheres?

535.—What pressure will be required to reduce ten liters of carbon dioxide at 15° C. to four liters at 2° C.?

536.—If one liter of carbon dioxide at 4° C. under a pressure of four atmospheres be warmed to 20° C., and the pressure at the same time reduced to 30 inches, what volume will the gas occupy?

537.—What is the weight of 1 cubic inch of ordinary air at 20° C. under 760 mm pressure?

538.—What is the weight of one cubic-decimeter of ordinary air at 20° C. under the ordinary atmospheric pressure?

CHAPTER III.

THE ABSORPTION OF GASES BY LIQUIDS.

The extent to which gases dissolve in liquids depends upon the kind of gas, the temperature, and the pressure.

Each gas has its own specific **co-efficient of absorption**, by which is meant the volume of gas absorbed by one volume of the solvent, at a given temperature, under 760 mm pressure.

The following are the co-efficients of absorption, at 0° C., under 760 mm pressure, of the gases named, respectively:

Hydrogen	0.0193
Nitrogen	0.02035
Oxygen	0.04114
Nitrous Oxide	1.3052
Carbon Dioxide	1.7967
Hydrogen Sulphide	4.3706
Sulphur Dioxide	7.9789

The volume occupied by the gas depends upon the temperature and pressure, as described in Chapter II.

In computing the volume of any gas dissolved, when that gas is mixed with another gas, it must be remembered that the pressure is in the same ratio as the proportion of that gas in the mixture. Thus, for instance, when one volume of water acts upon air at 0° C., under 760 mm pressure, the nitrogen, which constitutes $\frac{79}{100}$ of the volume of the air, is subject to $\frac{79}{100}$ of 760, and the oxygen is subject to $\frac{21}{100}$ of 760 mm pressure.

539.—If 100 Cc. of water at 10° C. dissolve 118 Cc. of carbon dioxide, how much carbon dioxide will be dissolved by a liter of water when shaken with air containing 0.05 per cent. of CO₂?

540.—The co-efficient of absorption of carbon dioxide being 1.7967, what volume of carbon dioxide will be dissolved by one liter of water at 10° C. under a pressure of two atmospheres?

541.—How much sulphur dioxide will be dissolved by two liters of water at 15° C., barometer at 30 inches?

542.—How much carbon dioxide will be dissolved by 20 gallons of water at 0° C., under the pressure of six atmospheres?

543.—What pressure is necessary to dissolve 300 cubic feet of carbon dioxide in 20 gallons of water at 15° C.?

544.—How many kilograms of carbon dioxide will be required to saturate 30 gallons of water at 0° C., under a pressure of 50 pounds to the square inch?

PART VI.

SPECIFIC DENSITY AND SPECIFIC VOLUME.

CHAPTER I.

INTRODUCTORY.

Matter is anything that is affected by gravitation, or that occupies space, or that is capable of motion. Whatever has weight or volume is, therefore, matter.

By **Mass** is meant the quantity of matter without regard to weight or volume.

The **Volume** of matter is the space it occupies.

Density is the relation of the mass of matter to its volume.

The **Specific Density** of any given kind of matter is the relation of mass to volume of that substance. Specific density is commonly called "specific gravity" and often also called "specific weight."

By **Specific Volume** we mean the relation of volume to mass of any substance.

Universal Gravitation is the force of attraction which is mutually operative between all bodies of matter in the universe.

Weight is the measure of the force with which any and all bodies of matter on or near the earth's surface are attracted by gravitation toward the earth's center.

The mass of matter is best measured by weight. **Mass** and **Weight** are, however, not equivalent or exchangeable terms, as will be seen from the foregoing definitions.

Mass, Volume and Density are necessarily expressed in terms referring to arbitrarily chosen units or standards of comparison.

The standard unit of mass for all countries, except Great Britain, is the prototype kilogram.

The standard unit of volume is, everywhere except in Great Britain, the volume of a kilogram of water at its maximum density (4° C.) **in vacuo**.

The standard unit of comparison for the expression of density is, for solids and liquids the density of water, and for gases the density of hydrogen.

The **Law of Archimedes** teaches that any body of matter suspended or immersed in any fluid is buoyed up (or pushed upward) by that fluid with a force the measure of which is the mass or weight of the fluid displaced by that body.

By "fluid" is here meant any liquid or any gas.

A cubic inch of metal in a tumbler containing enough water to quite cover all of the metal exerts a pressure upon the bottom of the tumbler which is equal **not** to the actual mass of that cubic inch of metal but equal only to that mass minus the mass of one cubic inch of water. The metal, of course, displaces its own volume of the water. In air the cubic inch of metal displaces its own volume of air and hence its apparent weight in air is not its true mass but is as much less than that as the weight of a cubic inch of air.

A solid body of less density than that possessed by water floats upon the latter and it descends in the water just far enough to displace its own **weight** (not its own **volume**) of the liquid. A balloon rises in the air whenever its whole bulk is lighter than the same volume of air. A pound of feathers weighed in the air against a brass weight on a balance is truly a commercial "pound of feathers," but its true weight is really more than a pound, for the feathers and the brass weight are both lifted up by the air displaced, each by the weight of its own volume, and the feathers are bulkier than the brass weight. To find the true weight of a commercial pound of feathers weighed in air we must add to it the weight of the air it displaces and deduct from the sum the weight of the air displaced by the weight used.

The **true specific density** of a solid or liquid is the quotient obtained by dividing its true weight or mass by the true weight or mass of the same volume of water at a given standard temperature.

But what we commonly mean by the term "specific gravity" is not the **true** but only the **apparent** specific density, for we find it by dividing the **weight in air** of the solid or liquid in question by the **weight in air** of the same volume of water.

Specific Density and Specific Volume of Water.

From "Calculations of Densities and Expansions," Standards Office, Board of Trade of Great Britain, July, 1883,* with interpolations by the Author.

Temperature.		Water at 4° C. (39.2 F.)=1.		Temperature.		Water at 4° C. (39.2 F.)=1.	
De- grees Centi- grade.	De- grees Fahren- heit.	Specific Volume. (In Vacuo.)	Specific Density. (In Vacuo.)	De- grees Centi- grade.	De- grees Fahren- heit.	Specific Volume (In Vacuo.)	Specific Density (In Vacuo.)
0.	32.	1.000123	0.999877	16.33	61.4	1.001060	0.998941
1.	33.8	1.000070	0.999930	16.67	62.	1.001118	0.998883
2.	35.6	1.000030	0.999970	17.	62.6	1.001177	0.998824
3.	37.4	1.000007	0.999993	17.33	63.2	1.001236	0.998765
4.	39.2	1.000000	1.000000	17.67	63.8	1.001296	0.998706
5.	41.	1.000009	0.999992	18.	64.4	1.001355	0.998647
6.	42.8	1.000031	0.999969	18.33	65.	1.001415	0.998587
7.	44.6	1.000070	0.999930	18.67	65.6	1.001478	0.998524
8.	46.4	1.000121	0.999879	19.	66.2	1.001543	0.998459
9.	48.2	1.000188	0.999813	19.33	66.8	1.001610	0.998393
10.	50.	1.000265	0.999735	19.67	67.4	1.001677	0.998326
11.	51.8	1.000356	0.999644	20.	68.	1.001746	0.998257
12.	53.6	1.000463	0.999537	21.	69.8	1.001954	0.998048
13.	55.4	1.000578	0.999422	22.	71.6	1.002174	0.997831
14.	57.2	1.000708	0.999293	23.	73.4	1.002399	0.997606
14.33	57.8	1.000756	0.999244	24.	75.2	1.002637	0.997370
14.67	58.4	1.000806	0.999195	25.	77.	1.002882	0.997126
15.	59.	1.000855	0.999145	26.	78.8	1.003140	0.996870
15.33	59.6	1.000906	0.999095	27.	80.6	1.003403	0.996608
15.56	60.	1.000939	0.999062	28.	82.4	1.003677	0.996336
15.67	60.2	1.000956	0.999045	29.	84.2	1.003961	0.996055
15.83	60.5	1.000981	0.999020	30.	86.	1.004257	0.995761
16.	60.8	1.001006	0.998995				

*Based upon the investigations of Despretz, Kopp, Pierre, Miller, Rosetti and Forster. The original values published by the Standards Office are printed in heavier type; the interpolations and computations by the Author are printed in lighter type.

**Table of Expansion of Dry Air at Different Temperatures from
0° C. to 22° C., bar. 760 mm, Taking the Volume
at 0° C. as 1.**

[Co-efficient of expansion = 0.003665 for each degree C.]

Temperatures.	Volumes.	Temperatures.	Volumes.
0.° C.....	1.000000	15.° C.....	1.054975
1.° C.....	1.003665	15.°6 C.....	1.057173
2.° C.....	1.007330	16.° C.....	1.058640
3.° C.....	1.010995	16.°67C.....	1.061096
4.° C.....	1.014660	17.° C.....	1.062305
5.° C.....	1.018325	18.° C.....	1.065970
6.° C.....	1.021990	19.° C.....	1.069635
7.° C.....	1.025655	20.° C.....	1.073300
8.° C.....	1.029320	21.° C.....	1.076965
9.° C.....	1.032985	22.° C.....	1.080630
10.° C.....	1.036650		

**Weight of Dry Air (Free from CO₂) Displaced by 1 Kilogram
of Metals of the Following Densities, Respectively:**

[Bar. 760 mm. Weight of 1 Liter of Air at 0°C.=1.293030 Gm.
No corrections have been made in these computations for the
cubical expansion of the metals.]

Special Wt. of the Metals. (Water at 4°C.—L.)	Volume Occu- pied by the Metals. Milliliters.	Weight in Milligrams of the Air Displaced.			
		At 4° C	At 15° C.	At 16.°67 C.	At 20° C.
21.60	46.296	58.997	56.743	56.415	55.774
21.55	46.404	59.135	56.875	56.547	55.904
21.50	46.512	59.272	57.007	56.679	56.034
21.45	46.620	59.410	57.140	56.810	56.164
21.40	46.729	59.549	57.273	56.943	56.296
21.35	46.838	59.688	57.407	57.076	56.427
21.30	46.948	59.828	57.542	57.210	56.559
21.25	47.055	59.964	57.673	57.340	56.688
21.20	47.170	60.111	57.814	57.480	56.827
21.15	47.281	60.253	57.950	57.616	56.961
8.60	116.279	148.180	142.517	141.695	140.084
8.55	116.959	149.046	143.351	142.524	140.903
8.50	117.647	149.923	144.194	143.362	141.732
8.45	118.343	150.810	145.047	144.210	142.571
8.40	119.048	151.709	145.911	145.070	143.420
8.35	119.760	152.616	146.784	145.937	144.278
8.30	120.482	153.536	147.669	146.817	145.148
8.25	121.212	154.466	148.563	147.707	146.027
8.20	121.951	155.408	149.469	148.607	146.917
8.15	122.699	156.361	150.386	149.519	147.818

CHAPTER II.

SPECIFIC DENSITY.

The specific densities of solids and liquids are expressed in water units; that is, the specific density of water is **one** (1.000). The specific density of any solid or liquid is therefore expressed by a number showing how many times the weight of a given volume of water is contained in the weight of the same volume of that solid or liquid.

The weight of a given volume of a solid or liquid being known, and the weight of the same volume of water being also known, we may find the specific density of the solid or liquid by the following simple rule: **Divide the weight of the solid or liquid by the weight of an equal volume of water; the quotient is the specific density sought.**

But the weight of a solid and the weight of an equal volume of water (the factors from which the specific density may be computed) can be found either directly or indirectly.

The respective weights of equal volumes of several different liquids may be found by weighing a solid body, first in air, and afterwards in each of those liquids in turn, the apparent loss of weight sustained by the solid when weighed in a liquid being always the weight of the same volume of that liquid. (See the "Law of Archimedes.") If the solid be weighed first in air and then in water, the difference between the two weights is the weight of the same volume of water.

Example:

If a cubic inch of metal is weighed first in air and then in water, the difference between its weight in air and its weight in water will be nearly 252.5 grains, because 1 cubic inch of water weighs nearly 252.5 grains.

If a solid measuring 1 Cc. be weighed first in air and then in ether, the difference between its weight in air and its weight in ether will be the weight of 1 Cc. of ether.

We can find

The specific densities of solids:

1. By dividing the weight of the solid by the weight of the same volume of water.

2. By weighing the solid first in air and then in water, and dividing the weight of the solid in air by its apparent loss of weight in water.

3. By dividing the weight of the solid in air by its apparent loss of weight in any liquid of known specific density, and multiplying the quotient by that specific density.

Explanation:—If a solid be weighed in a liquid having the specific density 0.900, then the weight of the same volume of water must be $\frac{10}{9}$ of the weight of the other liquid.

4. If a solid be dropped in water in a graduated cylinder, the increase of volume indicated by the graduations on the cylinder will show the volume of the solid. If therefore the weight of the solid in air be known, all that remains to be done, is to find the weight of the same volume of water, after which the usual division follows.

Should the cylinder be graduated in milliliters the rise of the water indicated in milliliters must show the weight of the same volume of water in Gm.

5. If the solid be lighter than water, we may nevertheless find its apparent loss of weight in water, or in other words, the weight of the same volume of water, by loading it down with a heavier solid so as to force it under water while weighing it, and then deducting the apparent loss of weight in water of the heavier solid, from the total loss of weight of both solids, which would leave as a remainder the loss of weight of the lighter solid, or the weight of its own volume of water.

6. A solid immersed in a liquid of the same specific density will neither sink nor float, but may be made to rest at any point in the body of the liquid. Hence, the specific densities of some solids may be ascertained by placing them in liquids in which they are insoluble, and then increasing or diminishing the specific density of the liquid as the case may require, until the solid floats about anywhere in the liquid, after which the specific density of the liquid is taken.

We may find

The specific densities of liquids:

1. By the aid of the pycnometer or "specific gravity bottle." The weight of the water which the pycnometer holds being already known, the weight of its contents of the other liquid is taken and divided by the weight of the water; the quotient being the specific density sought.

2. The weight of a given volume of any liquid ascertained directly or indirectly in any manner whatever, may be divided by the weight of the same volume of water.

3. A solid may be weighed first in water, and then in the liquid of which the specific density is to be found, and its apparent loss of weight in the latter liquid divided by its apparent loss of weight in water.

4. We may also take the specific density of any liquid by weighing in that liquid a solid of known mass and specific density, and finding its loss of weight in the liquid. Thus: If we know that a certain solid weighs 7 ounces and has the specific weight 7, and we find that it loses $1\frac{1}{4}$ ounces in weight when weighed in a certain liquid, then we of course know that the specific density of that liquid must be $1\frac{1}{4}$, since the same volume of water weighs 1 ounce.

5. Knowing the respective weights of equal volumes of any two liquids, we can easily compute the specific density of one, if we know the specific density of the other, for the knowledge of the specific weight of any liquid enables us to find the weight of the same volume of water.

6. The weight of a liter of any liquid in kilograms, expresses (very nearly) its specific density.

The weight of a ml of any liquid expressed in Gm, also expresses (very nearly) its specific density.

The weight of an Imperial fluidounce of any liquid expressed in avoirdupois-ounces, also expresses (very nearly) its specific density.

This is because the liter and the kilogram, the ml and the Gm, and the imperial fluidounce and the avoirdupois-ounce are, respectively, commensurate units.

The specific density of any liquid may accordingly be found

by dividing its weight in kilograms by its volume expressed in liters, or by dividing its weight in Gm by its volume in ml, or by dividing its weight in avoirdupois-ounces by its volume in Imperial fluidounces.

7. The specific density of any liquid may also be approximately found from the weight of 6 pints of it expressed in avoirdupois-ounces; that weight is to be divided by 100 and the quotient will be the specific density because 96 U. S. fluidounces of water weighs 100 avoirdupois-ounces.

Since the pharmacopœias and numerous other books use the common expression "specific gravity" instead of the more scientific term specific density we will use the abbreviation sp. gr. in these problems.

EXAMPLES.

545.—A piece of metal weighs 7 ounces; the same volume of water weighs 1 ounce; what is the sp. gr. of the metal?

546.—A one-thousand grain pycnometer holds 720 grains of ether; what is the sp. gr. of the ether?

✓ 547.—A bottle holds 480 grains of water, but 576 grains of nitric acid; what is the sp. gr. of that nitric acid?

548.—If twenty Imperial fluidounces of a liquid weigh $1\frac{1}{4}$ avoirdupois-pounds, what is the sp. gr. of that liquid?

549.—A fluidounce of alcohol at 22° C. weighs 373 grains, and a fluidounce of water at the same temperature weighs 455 grains; what is the sp. gr. of that alcohol referred to water at 22° C. as = 1.000?

550.—A liter of diluted alcohol weighs 925 Gm; what is the sp. gr. of that alcohol?

551.—A liter of glycerin weighs 1,250 Gm; what is its sp. gr.?

552.—If a bottle hold one-half ounce of water, but will hold five drachms of a certain solution of sodium carbonate, what is the sp. gr. of that solution?

✓ 553.—If one gallon of ether and one-half gallon of chloroform have the same weight, and two pints of chloroform weigh the same as three pints of water, what is the sp. gr. of the ether?

554.—If a graduated cylinder contain 30 ml of water, and if a solid weighing 13 Gm and dropped into the water raises the level of the water to 40 ml, what is the sp. gr. of the solid?

555.—The weight of 3 gallons of water is 400 avoirdupois-ounces, and the weight of 1 gallon of alcohol is 109 avoirdupois-ounces; what is the sp. gr. of the alcohol?

556.—An imperial-gallon of oil of peppermint weighs 9 avoirdupois-pounds; what is its sp. gr.?

557.—Six wine-pints of solution of zinc chloride weighs 155.5 avoirdupois-ounces; what is its sp. gr.?

558.—A cubic inch of a certain solid weighs 2,525 grains; what is its sp. gr.?

559.—Ten Cc. of a certain solid weighs 13 Gm; what is the sp. gr. of that solid?

560.—A solid weighs 4 Gm in air and 2.75 Gm in water; what is its sp. gr.?

561.—A certain solid weighs 150 grains; the same volume of water weighs 160 grains; what is the sp. gr. of the solid?

562.—A piece of metal of the bulk of 161.7 cubic inches weighs 347,624.55 grains in air, and 306,839.75 grains in water; what is the weight in grains of 231 cubic inches of water?

563.—A crystal weighs 10 Gm in air and 9 Gm in oil of turpentine, the sp. gr. of which is 0.860; what is the sp. gr. of the crystal?

564.—One Cc. of a certain solid weighs 870 milligrams; what is its specific weight?

565.—A piece of cork weighs .0732 Gm in air; a piece of metal weighs 7.7 Gm in air, but only 6.6 Gm in water; cork and metal tied together and weighed in water are found to weigh 4.182 Gm; what is the sp. gr. of the cork?

566.—A piece of lard is put in a vessel of water, and alcohol is added to the water gradually and mixed with it until the piece of lard, instead of floating on the surface, may be placed at will in any position in the body of the liquid. A 50 Gm pycnometer is now filled with the liquid, and the contents of the bottle found to weigh 46.9 Gm. What is the sp. gr. of the lard?

567.—If a piece of metal weigh 9 ounces in air, 8 ounces in water, and 8.1 ounces in oil, what is the sp. gr. of that oil?

568.—A solid measuring 10 ml when weighed immersed in oil of turpentine, is found to displace 8.6 Gm of the oil; what is the sp. gr. of the oil of turpentine?

569.—Glycerin has the sp. gr. 1.250; 3 volumes of glycerin has the same weight as 5 volumes of ether; what is the sp. gr. of the ether?

570.—50 Ce. of nitric acid weighs 71 Gm; 50 ml of hydrochloric acid weighs 58 Gm; the sp. gr. of the hydrochloric acid is 1.160; what is the sp. gr. of the nitric acid?

571.—A certain bottle holds 100 ounces of glycerin, the sp. gr. of which is 1.250; how many ounces will that bottle hold of water?

572.—How much will the same bottle hold of ether, having the sp. gr. 0.720?

573.—How much will it hold of chloroform of the sp. gr. 1.470?

574.—How much will it hold of syrup having the sp. gr. 1.330?

575.—How much will it hold of alcohol having the sp. gr. 0.820?

576.—A solid weighing 3 ounces, and having the sp. gr. 8, loses $\frac{1}{2}$ oz. in weight when weighed in a certain liquid. What is the sp. gr. of that liquid?

CHAPTER III.

SPECIFIC VOLUME.

The term specific volume was suggested by the author of this book in 1883,* to express the relative volume of any liquid, as compared with the volume of an equal weight of water. The specific volumes of substances are the reciprocals of their specific densities. If the sp. gr. exceeds 1, the sp. vol. is less than 1, and vice versa. The specific volume of any liquid may be found:

1. By dividing 1 by the specific density.

Thus, if the specific density be expressed in the form of a common fraction, the specific volume is obtained by turning the common fraction upside down.

Ex.:—If the specific density is $\frac{1}{2}$, the specific volume is $\frac{2}{1}$; if the specific density is $\frac{9}{10}$, the specific volume is $\frac{10}{9}$; if the specific density is $\frac{3}{4}$, the specific volume is $\frac{4}{3}$, etc.

(As a matter of course, the specific density of any liquid can be deduced in a similar manner from the specific volume.)

2. The specific volume of a liquid may also be found, by dividing the volume of a given weight of any liquid by the volume of the same weight of water.

3. The specific volume of any liquid is also found by dividing the weight of a given volume of water by the weight of an equal volume of the other liquid.

EXAMPLES.

577.—The sp. gr. of water being 1, what is its sp. vol.?

578.—If the sp. gr. of a certain liquid be 1.500, what is its sp. vol.?

*See Proceedings of the Amer. Phar. Association for that year.

579.—If the sp. gr. of a certain liquid is 0.800, what is its sp. vol.?

580.—The sp. gr. being 0.400, what is the sp. vol.?

581.—The sp. gr. being 1.250, what is the sp. vol.?

582.—One kilogram of a liquid measures 750 ml; what is the sp. vol.?

583.—One hundred avoirdupois-ounces of a liquid measures 6 pints; what is its sp. vol.?

584.—If 300 Gm of a liquid measure 280 ml, what is its sp. vol.?

585.—If four Imperial-pints of a liquid weigh 6 lb, what is its sp. vol.?

586.—If 5 lb of a liquid measure 70 Imperial fluidounces, what is its sp. vol.?

587.—If one liter of a certain liquid weigh 1,200 Gm, what is its sp. vol.?

588.—If 300 ml of a liquid weigh 280 Gm, what is its sp. vol.?

589.—10 ml of a solution weighs 15 Gm, what is the specific volume of the solution?

590.—10 ml of a liquid weighs 6.66 Gm, what is the specific volume of that liquid?

591.—A certain solid weighed in water sustains an apparent loss of weight of 1 ounce; weighed in ether it sustains an apparent loss of $\frac{3}{4}$ of an ounce; what is the specific volume of the ether?

592.—One ounce of a certain solution measures 35 ml, while an ounce of water measures 30 ml; what is the specific volume of the solution?

593.—A certain solid measures 10 ml, and weighs 9 Gm; what is its specific volume?

594.—A solid body displaces 1 ounce of water and .9 ounces of oil; what is the specific volume of the oil?

CHAPTER IV.

HOW TO FIND THE WEIGHTS OF GIVEN VOLUMES AND THE VOLUMES OF GIVEN WEIGHTS OF LIQUIDS.

1. To find the weight of any number of liters of any liquid, the specific weight of which is known: **Multiply the liters by the specific density; the answer is the weight expressed in kilograms.**

To find the weight in Gm of any number of ml: **Multiply by the specific density.**

To find the weight in avoirdupois-ounces of any number of Imperial fluidounces: **Multiply by the specific density.**

2. To find the weight of 6 pints of any liquid of which the specific density is known: **Multiply the specific density by 100; the answer is the weight sought, expressed in avoirdupois-ounces.**

3. We may also find the weight of any given volume of any liquid by **multiplying the weight of the same volume of water by the specific density of the other liquid.**

We may also find the weight of any given volume of water from the weight of an equal volume of any other liquid, the specific density of which is known, **by dividing the weight of that liquid by its specific density.**

4. To find the volume of any number of kilograms of any liquid, the specific density of which is known: **Multiply the number of kilograms by the specific volume of the liquid; the answer expresses the volume in liters.**

5. The volume of any number of Gm expressed in ml will be obtained by **multiplying the Gm by the specific volume.**

6. The volume of any number of avoirdupois-ounces will be found in Imperial fluidounces by **multiplying by the specific volume.**

7. The volume of 100 avoirdupois-ounces of any liquid will be found expressed in American fluidounces by **multiplying**

the specific volume by 96; or it will be found in pints by multiplying the specific volume by 6.

N. B.—A multiplication by the specific density gives the same result as a division by the specific volume; and a division by the specific density gives the same result as a multiplication by the specific volume.

EXAMPLES.

595.—What is the weight of 250 ml of a liquid having the sp. gr. 1.100?

596.—What is the weight of one liter of a liquid of 0.900 sp. gr.?

597.—What is the weight of one liter of a liquid having the sp. gr. 1.320?

598.—What is the weight of 30 ml of a liquid having the sp. gr. 0.720?

599.—What is the weight, in avoirdupois-ounces, of an Imperial-pint of a liquid having the sp. gr. 1.160?

600.—What is the weight, in avoirdupois-ounces, of 100 Imperial fluidounces of a liquid having the sp. gr. 0.960?

601.—What is the weight, in pounds, of an Imperial gallon of a liquid having the sp. gr. 1.300?

602.—What is the weight, in avoirdupois-ounces, of 6 wine-pints of a liquid having the sp. gr. 0.820?

603.—What is the weight, in avoirdupois ounces, of 3 apothecaries' pints of a liquid having the sp. gr. 1.250?

604.—What is the weight, in avoirdupois-ounces, of 16 American fluidounces of a liquid having the sp. gr. 1.260?

605.—If a cubic inch of water weigh 252.50 grains, what is the weight of 231 cubic inches of a liquid having the sp. gr. 0.900?

606.—If one American fluidounce of water weigh 0.95 apothecaries' ounce, what is the weight of one fluidounce of a liquid having the sp. gr. 0.860?

607.—What will 3 kilograms of nitric acid measure if its sp. gr. is 1.420?

608.—What is the volume of 640 Gm of a liquid having the sp. vol. 0.800?

609.—What is the volume of 1 kilogram of a liquid having the sp. vol. 1.200?

610.—What is the volume of 800 Gm of any liquid having the sp. vol. 0.900?

611.—What is the volume of a pound of olive oil, its sp. vol. being 1.091? Give the answer in Imperial fluidounces.

612.—What is the volume of 100 avoirdupois-ounces of olive oil? Give the answer in American fluidounces.

613.—What is the volume of 100 avoirdupois-ounces of olive oil, expressed in pints?

614.—What is the volume of 5 lb of any liquid having the sp. vol. 1.111? Give the answer in pints?

615.—Castor-oil has the sp. vol. of 1.042. What is the volume of 6 lb, stated in American fluidounces?

CHAPTER V.

MISCELLANEOUS PROBLEMS IN THE RELATIONS OF WEIGHT AND VOLUME.

616.—A piece of metal weighs 6,445.380 grains in air; in water it weighs 5,585.996 grains; its bulk is 340 cubic inches. What is the sp. gr. of the metal, and what is the weight of a cubic inch of water?

617.—A piece of metal weighs 480 grains in air, 400 grains in a solution of sugar, and 420 grains in water. What is the volume of 500 Gm of that sugar solution?

618.—One liter of water at 4° C. weighs, *in vacuo*, one kilogram. Does it weigh more or less than 1,000 Gm when weighed in air?

619.—Which is the heavier, a kilogram weight of brass or a kilogram weight of platinum when both are weighed in a vacuum? in air?

620.—Which is really heavier, a pound of wood or a pound of lead?

621.—A solid measuring 0.1 cubic decimeter is weighed first *in vacuo*, then in air, and lastly in water; one cubic inch of air weighs 0.3 grains, and a cubic inch of water 252.50 grains.

Find:

a) The difference between the weight of that solid *in vacuo* and its weight in air.

b) The difference between its weight in air and its weight in water.

622.—The weight of air and of water being assumed to be as stated in problem 621, what is the weight of a cubic inch of metal having the sp. gr. 10.000?

623.—A ten-dollar gold coin weighs 258 grains in air; assuming its sp. gr. to be 18.300, what is its apparent loss of weight when weighed suspended in water?

624.—The sp. gr. of chloroform being 1.500, what is the weight of 900 ml?

625.—What is the weight of one liter of any liquid having the sp. gr. 0.750?

626.—What is the volume of 370 Gm of any liquid of 0.800 sp. gr.?

627.—If an Imperial-gallon of sulphuric acid weigh 18.35 avoirdupois-pounds, what is the volume of 1,000 Gm of that acid expressed in ml?

628.—If an Imperial pint of syrup weigh 26 avoirdupois-ounces, what is the volume of 1 kilogram of that syrup?

629.—If the sp. gr. of oil of vitriol be twice that of olive oil, and if one liter of olive oil weigh 917 Gm, what is the weight of 500 ml of oil of vitriol?

630.—If a solid weigh 75 ounces, and the same volume of water 10 ounces, what is the apparent weight of that solid when weighed suspended in water?

631.—If a bullet weigh 13 ounces in air and 12 ounces in water, what will it appear to weigh in a liquid having 1.400 sp. gr.?

632.—If a pound of water measure $15\frac{3}{8}$ fluidounces, and a pound of a certain solution $7\frac{11}{16}$ fluidounces, what is the specific volume of that solution?

633.—What number of ml expresses the volume of 85.33 Gm of a liquid having 1.01 sp. vol.?

634.—What number of Gm expresses the weight of 13,476 liters of a liquid having 1.100 sp. gr.?

635.—What is the weight of one liter solution of mercury nitrate, in kilograms, the sp. gr. being 2.100?

636.—A solution of citrate of iron has the sp. gr. 1.260; what is the weight of one wine-pint, in avoirdupois-ounces?

637.—The sp. gr. of oil of turpentine being 0.860, what is the weight of 96 American fluidounces of it, in avoirdupois-ounces?

638.—Which is the greater, the number expressing the sp. gr. of acetic acid referring to water at 4° C. as unit, or the number expressing the sp. gr. of the same acid referring to water at 15° C. as unit?

639.—A certain liquid at 39.2° F. has the sp. gr. 1.200 referring to water at 22° C. as unit; will the number expressing its sp. gr. at 60° F., referring to water at 4° C. as unit, be greater or less than 1.200?

640.—The weight of one liter of water at 4° C. is 15,424 grains; but the weight of 500 ml of water at 22° C. is 7,696 grains. **a)** What is the sp. gr. of water at 22° C. referring to water at 4° C. as a unit? and **b)** what is the sp. gr. of water at 4° C., referring to water at 22° C. as = 1.000?

641.—An Imperial gallon of water at 62° F., barometer at 30 inches, weighs 70,000 grains; **a)** does it weigh more or less at 15° C.? and **b)** does it weigh more or less when the atmospheric pressure is greater?

642.—A cubic inch of water at 22° C. weighs 252.5 grains. What is the weight of one wine-gallon of an alcohol having 0.860 sp. gr., referring to water at 22° C. as = 1.000?

643.—What is the volume of 100 apothecaries' ounces of oil of 0.900 sp. gr., if one cubic inch of water weighs 252.5 grains?

644.—A liquid has the sp. gr. of 0.950; what is its sp. vol.?

645.—The sp. vol. of a liquid is 0.800; what is its sp. gr.?

646.—What is the specific volume corresponding to each of the following specific densities, respectively:

a) 1.000?	b) 1.250?	c) 1.333?
d) 0.500?	e) 0.750?	f) 0.800?
g) 2.000?	h) 0.720?	i) 0.820?
k) 1.500?	l) 1.300?	m) 1.320?

647.—What is the volume of 1,000 Gm of a liquid having the sp. vol. 1.200?

648.—What is the volume, in Imperial fluidounces, of 100 avoirdupois-ounces of a liquid having the sp. vol. 0.800?

649.—What is the volume in American fluidounces of 25 avoirdupois-ounces of a liquid having the sp. vol. 1.000?

650.—What number of ml expresses the volume of 85 Gm of a liquid having the sp. gr. 1.010?

651.—What number of ml expresses the volume of 85 Gm of a liquid having the sp. vol. 1.010?

652.—What number of Gm expresses the weight of 85 ml of a liquid having the sp. gr. 1.010?

653.—What number of Gm expresses the weight of 85 ml of a liquid having the sp. vol. 1.010?

654.—The total weight of a bottle filled with water is 30 ounces. The same bottle filled with olive oil weighs 28 ounces. What is the weight in ounces of the water the bottle is capable of holding? How many ounces of oil will it hold and what is the tare of the bottle?

655.—A bottle filled with water weighs 16 ounces; filled with chloroform having the specific gravity 1.470, it weighs 19.877 ounces; filled with acid it weighs 17.32 ounces. What is the weight of the bottle? How much does it hold of water, chloroform, and acid, respectively and what is the specific gravity of the acid?

656.—A solid measuring 2 cubic inches weighs 6,000 grains in the air, but only 5,400 grains when weighed suspended in a certain liquid; what is the sp. gr. of that liquid?

657.—A solid measuring 10 ml loses 1 Gm in weight when weighed in a certain liquid; what is the sp. gr. of that liquid?

658.—Alcohol has the sp. gr. 0.820 at 15.°6 C. (60°F.). The net weight of a barrel of alcohol at that temperature is found to be 300 $\frac{2}{3}$ pounds. How many gallons of alcohol does that barrel contain?

659.—*In what proportions should glycerin and water be mixed, to produce a mixture having the specific gravity 1.100?

660.—*In what proportions must glycerin and alcohol be mixed, to produce a liquid of the density of water?

661.—*A certain mixture of water and syrup has the specific gravity 1.20; what are the proportions of syrup and water in the mixture?

662.—*What will be the specific gravity of a mixture of equal parts by weight of alcohol, glycerin and water?

663.—How many avoirdupois-ounces will a pint bottle hold of a liquid having 1.310 sp. gr.?

664.—How many Gm of a liquid of 0.800 sp. gr. will fill a bottle of 800 Cc. capacity?

*—The specific gravity of glycerin is 1.250; that of alcohol 0.820; that of syrup 1.330.

665.—How large a bottle is required to hold ten pounds of a liquid of:

- | | |
|-------------------|-------------------|
| a) 0.700 sp. gr.; | b) 0.900 sp. gr.; |
| c) 1.000 sp. gr.; | d) 1.160 sp. gr.; |
| e) 1.432 sp. gr.; | f) 1.835 sp. gr.? |

Give the answers in American pints.

666.—Of what capacity in Ce. must the bottle be to hold one kilogram of liquid of:

- | | |
|--------------------|--------------------|
| a) 0.600 sp. vol.; | b) 0.800 sp. vol.; |
| c) 1.200 sp. vol.; | d) 1.500 sp. vol.; |
| e) 1.250 sp. gr.; | f) 0.720 sp. gr.? |

CHAPTER VI.

CORRECTIONS FOR TEMPERATURE IN TAKING SPECIFIC DENSITIES, ETC.

The specific densities of liquids vary according to the temperature. Corrections are therefore made for expansions or contractions at higher or lower temperatures when the observations have been taken at other temperatures, as may be required. These corrections may be made in accordance with observed "differences," or by the aid of observed "co-efficients of expansion."

Each liquid has its own **co-efficient of expansion**; and in mixtures the co-efficient of expansion depends upon the proportions of the ingredients of the mixture.

Tables of differences and co-efficients of expansion are necessary to facilitate the work of making due corrections for differences of temperature.

When the **difference** for each degree above or below the standard temperature has been ascertained, that difference is simply multiplied by the number of degrees and added to or deducted from the observed specific density, as the case may require.

When corrections are made by means of co-efficients of expansion, the rules are as follows:—Designating the observed specific density as **a**, the co-efficient of expansion as **b**, the number of degrees difference by the thermometric scale as **c**, and the corrected specific density sought as **x**, we have:—

Rule I.—For correcting specific density observed at a higher temperature to the specific density at a given lower temperature:

$$\frac{a}{1-(b \times c)} = x.$$

Rule II.—For correcting specific density observed at a lower temperature to the specific density at a given higher temperature:

$$\frac{a}{1+(b \times c)} = x.$$

Tables of differences and co-efficients of expansion are given in the Pharmacopœia of the United States, VIII.

EXAMPLES.

667.—If the sp. gr. of a 10 per cent. alcohol at 15°C. is 0.9839, what will be the sp. gr. of the same alcohol at 20°C.?

668.—If the sp. gr. of a 20 per cent. alcohol at 20°C. be 0.970, what is the sp. gr. of the same alcohol at 12°C. and at 22°C.?

669.—What correction should be made in the sp. gr. of an alcohol of about 50 per cent. strength, the observation being taken at 25°C.?

670.—If the sp. gr. of hydrochloric acid at 20°C. be 1.120, what is its sp. gr. at 62°F.?

671.—If the observed sp. gr. of nitric acid at 66°F. be 1.360, what is its sp. gr. at 15°C.?

672.—If the observed sp. gr. of sulphuric acid at 70°F. be 1.820, what is its sp. gr. at 15°C.? and at 22°C.?

673.—If the observed sp. gr. of an alcohol at 20°C. be 0.8796, what is the percentage strength of that alcohol?

674.—If the sp. gr. of an alcohol, taken at 15°C., be found to be 0.8796, what is its percentage strength?

675.—If the observed sp. gr. of alcohol at 22°C. be 0.820, what correction should be made to get its sp. gr. at 15.6°C.? and at 62°F.?

676.—If the sp. gr. of a sample of alcohol at 62°F. be found to be 0.8227, what is the percentage strength?

677.—If the alcoholometer when placed in a jar of alcohol indicates 60 per cent. at a temperature of 55°F., what is the percentage strength of that alcohol at the standard temperature of the Revenue Service?

678.—If the sp. gr. of alcohol taken at 15°C. be 0.870, what is the sp. gr. at 22°C.? and at 20°C.?

679.—If the sp. gr. of alcohol observed at 20°C . be 0.889, what would be its sp. gr. at 15°C .?

680.—If the sp. gr. of an ammonia solution at 21°C . be 0.900, a) what is its sp. gr. at 15°C .? and b) at 14°C .?

681.—If alcohol at 22°C ., when tested by the alcoholometer, appears to be 20 degrees above proof, what is its real strength in degrees proof by the standard of the Revenue Service?

682.—If the observed sp. gr. of hydrochloric acid be 1.140 at 22°C ., what is its sp. gr. at 15°C .? and at 20°C .?

683.—If the observed sp. gr. of nitric acid be 1.400 at 18°C ., what is its sp. gr. at 22°C .? and at 15°C .?

684.—If the sp. gr. of acetic acid at 22°C . be 1.070, what is its percentage strength, and what is its sp. gr. at 15°C .? and at 62°F .?

685.—If the observed sp. gr. of a sulphuric acid at 21°C . be 1.700, what is its sp. gr. at 18°C .? and at 15°C .?

686.—What is the weight of 1 liter of water at 4°C . in air, weighed with brass weights of 8.3 sp. gr.?

687.—Weight of 1 liter of water at 15°C . in air?

688.—Weight at $15.^{\circ}6$ (60°F .) in air?

689.—Weight at $16.^{\circ}67$ (62°F .) in air?

690.—Weight at 20°C . in air?

691.—Weight at 22°C . in air?

692.—Weight at 25°C . in air?

693.—Weight of 1 fluidounce in air at 20°C .?

694.—Weight of 1 cubic inch in air at 22°C .?

695.—Weight of 1 pint in air at 15°C .?

CHAPTER VII.

BAUMÉ DEGREES REDUCED TO SPECIFIC GRAVITY AND VICE VERSA.

The rules here given refer to the Baumé scales used in America and to the temperature of 60° F.

Liquids Heavier than Water.

Rule I.—To convert Baumé degrees into specific gravity:—Divide 145 by 145 minus the number of degrees Baumé:

$$\frac{145}{145 - B^{\circ}} = \text{Sp. gr.}$$

Rule II.—To convert specific gravity into the corresponding degree Baumé:—Divide 145 by the specific gravity; subtract the quotient from 145. the remainder is the corresponding degree Baumé:

$$145 - \frac{145}{\text{Sp. gr.}} = B^{\circ}$$

For Liquids Lighter than Water.

Rule III.—To convert any number of Baumé degrees to specific gravity:—Divide 140 by 130 plus the number of degrees Baumé; the quotient is the specific gravity:

$$\frac{140}{130 + B^{\circ}} = \text{Sp. gr.}$$

Rule IV.—To convert specific gravity into the corresponding number of degrees Baumé:—Divide 140 by the specific gravity, and from the quotient subtract 130; the remainder is the number of degrees Baumé sought:

$$\frac{140}{\text{Sp. gr.}} - 130 = B^{\circ}$$

The Baumé hydrometer for heavy liquids is called an "acidometer"; that for lighter liquids is called a "spirit hydrometer."

EXAMPLES.

696.—Reduce 20 degrees of Baumé's acidometer to sp. gr.

697.—Reduce 16 degrees of Baumé's spirit hydrometer to sp. gr.?

698.—Reduce 30 degrees of Baumé's spirit hydrometer to sp. gr.?

699.—Reduce 40 degrees of Baumé's acidometer to sp. gr.

700.—Reduce sp. gr. 1.42 to degrees Baumé.

701.—Reduce 0.720 sp. gr. to Baumé degrees.

702.—Reduce 0.960 sp. gr. to Baumé degrees.

703.—Reduce 1.250 sp. gr. to Baumé degrees.

704.—Reduce 0.900 sp. gr. to Baumé degrees.

705.—Reduce 0.860 sp. gr. to Baumé degrees.

706.—Reduce 1.160 sp. gr. to Baumé degrees.

707.—Reduce 1.843 sp. gr. to Baumé degrees.

708.—Reduce 26° Baumé's spirit hydrometer to sp. gr.

709.—Reduce 18° Baumé's spirit hydrometer to sp. gr.

710.—Reduce 20° Baumé's acidometer to sp. gr.

711.—Reduce 43° Baumé's acidometer to sp. gr.

712.—Reduce 10° Baumé's acidometer to sp. gr.

PART VII.

DIMENSIONS, SURFACE AND CAPACITY.

Rule I.—To find the area of a circle, the diameter being known:—**Multiply the square of $\frac{1}{2}$ the diameter by 3.1416.**

Rule II.—To find the diameter of a circle, the area of which is known:—**Divide the area by 3.1416; the square root of the quotient is equal to $\frac{1}{2}$ the diameter.**

Rule III.—To find the solidity of a prism or cylinder:—**Multiply the area of the base by the perpendicular height.**

Rule IV.—To find the solidity of any pyramid or cone:—**Multiply the area of the base by $\frac{1}{3}$ of the altitude.**

Rule V.—To find the solidity of the frustum of a pyramid or of a cone:—**Multiply the areas of the two bases together, and extract the square root of the product. This root is the area of a base which is a mean between the other two. Take the sum of the areas of the three bases, and multiply it by $\frac{1}{3}$ of the altitude. The product is the solidity of the frustum.**

Rule VI.—To find the solidity of a sphere:—**Multiply the cube of the diameter by 3.1416, and divide the product by 6; or Multiply the area of the surface by $\frac{1}{6}$ of the diameter.**

713.—What is the area of a spread plaster in circular form, the diameter of which is 30 centimeters?

714.—What is the square surface of a filter paper of 6 inches diameter?

715.—What is the diameter of a circular blister measuring 3 square inches?

716.—What is the capacity of a cylindrical tincture bottle of 6 inches internal diameter and 12 inches height?

717.—What is the capacity of a funnel of $6\frac{1}{2}$ inches internal diameter at the top, and measuring $5\frac{1}{2}$ inches inside from the top to the throat?

718.—What is the capacity of a cylindrical percolator 12 inches high and of 2 inches internal diameter?

719.—What is the capacity of a cylindrical percolator 12 inches high and of $2\frac{1}{2}$ inches internal diameter?

720.—What is the capacity of a conical percolator $1\frac{1}{2}$ inches in diameter at the bottom, 2 inches diameter at the top, and 10 inches high, inside measurements?

721.—What is the solidity of a globe 10 inches in diameter?

CHEMICAL PROBLEMS AND EXERCISES

WITH INTRODUCTORY CHAPTERS ON ELEMENTARY
THEORETICAL CHEMISTRY AND THE PERIODIC SYSTEM.

CLASSIFICATION AND NOMENCLATURE OF INORGANIC
CHEMICAL COMPOUNDS.

CHEMICAL NOTATION.

CHEMICAL REACTIONS. EQUATION WRITING.

OXIDATION AND REDUCTION.

STECHEIOMETRIC PROBLEMS

CHEMICAL PROBLEMS AND EXERCISES.

CHAPTER I.

REVIEW COURSE IN ELEMENTARY THEORETICAL CHEMISTRY.

1. Students of chemistry must master chemical notation and nomenclature, and learn to write chemical equations correctly and with facility before they can make much progress. So important is the mastery of notation and equation writing that without it the student may be said to know nothing of chemistry, while the possession of that accomplishment goes far to prove him well equipped for further advance.

The requisite mastery of chemical notation and equation writing can be acquired only by sufficient **practice**, and the object of these pages is to present material such as may be advantageously employed for that purpose.

A brief review of certain portions of elementary theoretical chemistry directly applicable to the task before us will render it easier.

2. About eighty distinct kinds of so-called elemental matter are now known (1907).

These chemical **elements** may be but distinctive forms of one universal **primary matter**, and it is possible that one element may be convertible into another, or that a substance now called an element may be a compound. But even if the "unity of matter" should be demonstrated, and several of the kinds of matter now recognized as elements shown to be compounds, it is evident that the kinds of matter known as elements must still continue to be the same distinct substances as before.

3. **Atoms** are the smallest particles of matter capable of

entering into chemical combination with each other to form other kinds of matter. All atoms of the same element are assumed to have the same mass, while the atoms of one element differ from those of any other element.

Atoms were formerly defined as "indivisible particles" of matter. It is now believed that they are divisible into far smaller particles called "electrons." But the divisibility of an atom into thousands or many thousands of electrons does not do away with it. Practical chemistry must still continue to deal with atoms and atomic weights as before, and our chemical notation will probably long remain as now.

It was once held that atoms can not exist alone or singly. But it is now believed that matter can and does exist in nature in the form of single uncombined atoms. There are strong grounds for the assumption that the recently discovered elements helium, neon, argon, krypton and xenon contained in the air must consist of free atoms even at the ordinary temperature. Other elements, as, for instance, chlorine, bromine, iodine, mercury and zinc, have long been assumed to exist in the form of single atoms at sufficiently high temperatures.

4. The known elements are enumerated in the following table:

The names of the most common and important elements including those contained in commercial and medicinal substances, are printed in heavy-faced type.

The names in the second column are in most cases coined words which are not Latin but simply latinized or latinic in form.

******Elements marked with two stars are the typical so-called non-metallic elements.

*****Elements marked with one star exhibit physical properties resembling those commonly possessed by metals, but they resemble the non-metallic elements in their chemical properties and behavior, and are accordingly properly called non-metallic elements.

†Elements marked with a dagger are metals.

Elements not known to form any chemical compounds are printed in italics.

TABLE OF THE CHEMICAL ELEMENTS WITH THEIR ATOMIC WEIGHTS.

Common Name.	Latin Name.	Symbol.	Approximate Relative Weight of the Atom. (Atomic Weight.)
Aluminum †	Aluminum	Al	27
Antimony * †	Antimonum or Stibium	Sb	120
<i>Argon</i>	Argonum	A	39?
Arsenic *	Arsenum	As	75
Barium †	Barium	Ba	137
Beryllium †	Beryllium	Be	9
Bismuth †	Bismuthum	Bi	208
Boron **	Borum	B	11
Bromine **	Bromum	Br	80
Cadmium †	Cadmium	Cd	112
Cæsium †	Cæsium	Cs	133
Calcium †	Calcium	Ca	40
Carbon **	Carboneum	C	12
Cerium †	Cerium	Ce	140
Chlorine **	Chlorum	Cl	35.5
Chromium †	Chromium	Cr	52
Cobalt †	Cobaltum	Co	59
Columbium †	Columbium	Cb	94
Copper †	Cuprum	Cu	63.5
Erbium †	Erbium	Er	166
Fluorine **	Fluorum	F	19
Gallium †	Gallium	Ga	70
Germanium **	Germanium	Ge	72
Gold †	Aurum	Au	197
Helium	Helium	He	4
Hydrogen **	Hydrogenium	H	1
Indium †	Indium	In	114
Iodine **	Iodum	I	126.5
Iridium †	Iridium	Ir	193
Iron †	Ferrum	Fe	56
<i>Krypton</i>	Kryptum	Kr	82
Lanthanum †	Lanthanum	La	138
Lead †	Plumbum	Pb	207
Lithium †	Lithium	Li	7
Magnesium †	Magnesium	Mg	24.5
Manganese †	Manganum	Mn	55
Mercury †	Hydrargyrum	Hg	200
Molybdenum †	Molybdenum	Mo	96
Neodymium †	Neodymium	Nd	143
<i>Neon</i>	Neum	Ne	20
Nickel †	Niccolum	Ni	58.5
Nitrogen **	Nitrogenium	N	14
Osmium †	Osmium	Os	191
Oxygen **	Oxygenium	O	16
Palladium †	Palladium	Pd	106
Phosphorus **	Phosphorus	P	31
Platinum †	Platinum	Pt	195
Pollonium †	Pollonium	Po	?
Potassium †	Potassium or Kalium	K	39
Praseodymium †	Praseodymium	Pr	140.5

CHEMICAL ELEMENTS WITH THEIR ATOMIC WEIGHTS—CONTINUED.

Common Name.	Latinic Name.	Symbol.	Approximate Relative Weight of the Atom. (Atomic Weight.)
Radium †	Radium	Ra	227
Rhodium †	Rhodium	Rh	103
Rubidium †	Rubidium	Rb	85.5
Ruthenium †	Ruthenium	Ru	101.5
Samarium †	Samarium	Sm	150
Scandium †	Scandium	Sc	44
Selenium **	Selenium	Se	79
Silicon **	Silicium	Si	28.5
Silver †	Argentum	Ag	108
Sodium †	Sodium or Natrium	Na	23
Strontium †	Strontium	Sr	88
Sulphur **	Sulphur	S	32
Tantalum †	Tantalum	Ta	183
Tellurium *	Tellurium	Te	127
Terbium †	Terbium	Tb	160
Thallium †	Thallium	Tl	204
Thorium †	Thorium	Th	233
Tin †	Stannum	Sn	118.5
Titanium †	Titanium	Ti	48
Tungsten †	Wolframium	W	184
Uranium †	Uranium	U	240
Vanadium †	Vanadium	V	51.5
Xenon	Xenum	X	128
Ytterbium †	Ytterbium	Yb	173
Yttrium †	Yttrium	Yt	89
Zinc †	Zincum	Zn	65.5
Zirconium †	Zirconium	Zr	90.5

Helium, neon, argon, krypton and xenon are gaseous elements recently discovered in the atmosphere; all efforts so far made to cause these elements to enter into chemical combination with any other elements have been unsuccessful. All of these elements belong to one natural group in the periodic system.

Oxygen and fluorine combine with hydrogen but not with each other.

Oxygen combines with all elements except those mentioned in these paragraphs.

5. The **atomic weight** of an element is the mass of its atom, or, in other words, its mass unit of chemical combination.

6. With regard to composition, structure and divisibility all particles of matter may be classified into:

a. Atoms existing singly.

b. Molecules or groups of atoms in chemical combination with each other in accordance with the requirements or limitations of what we term "valence" (par. 16).

c. Chemical combinations of molecules in definite proportions.

d. Particles of matter consisting of more than one kind of molecules which are not held together by chemical energy or in definite proportions. Such particles of matter are mixtures, not chemical compounds.

In this text we shall consider only atoms, molecules and molecular combinations.

7. **Chemical energy** or chemism is that form of energy by which atoms are held in combination with or attracted to each other, and by which changes of atomic combinations are effected. It is the energy by which existing forms of matter resist change, and yet, at the same time, the energy by which individual kinds of matter may be transformed into other individual kinds of matter, according to the relative "affinities" of different kinds of atoms for each other. Chemical composition and decomposition and all possible chemical changes are controlled or directed by chemical energy however much chemism may be affected by external conditions.

Chemical energy and electrical energy are believed to be identical.

8. The specific chemical energy of any element is directly related to its atomic weight as evidenced by the Periodic Law (Chapter II.). The individuality of each element is more or less marked. The elements most nearly resembling each other do not usually enter into combination with each other, while those that differ widely exhibit marked mutual "affinities" or tendencies to combine.

Chemical combining power may be considered as to its intensity (par. 9), quality (par. 10), and quantity (par. 16). These are all relative properties.

The specific chemical properties of individual elements are greatly affected by temperature, pressure, the properties of oth-

er elements with which they come in contact or with which they are in chemical combination, the properties of the compounds they may form, the relative proportions of substances acting upon each other, and by various other conditions.

9. The **intensity** of the chemical energy of different elements varies greatly. Thus the energy with which fluorine, chlorine, bromine, phosphorus, potassium and sodium enter into combination with certain other elements appears to be decidedly intense, while the inclination of boron, silicon, carbon, nitrogen, gold and platinum to form chemical compounds seems comparatively feeble under ordinary conditions. The striking differences between different elements in this respect are among the facts which every observing student of chemistry learns early in the laboratory. (See also par. 38.)

10. The quality of the chemical combining power of any element is called its **polarity**. The polarity of chemical combining energy is either **positive** or **negative**.

a. Any two atoms in immediate chemical combination with each other are of opposite polarities to the extent to which their combining power is exercised in holding them to each other. Thus in any particle of matter composed of but two atoms one of those atoms is of positive polarity and the other of negative polarity. This is true whether the two atoms are of the same element or of different elements.

b. In any strictly binary compound (par. 51) consisting of two elements united directly to each other in such a way that each and every atom of one element is in immediate combination with each and every atom of the other element (so that each atom of any one of the two elements has the same valence as any other atom of the same element), one of the elements is relatively a "positive element" and the other a "negative element."

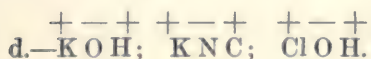
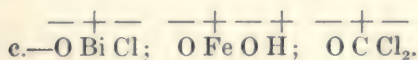
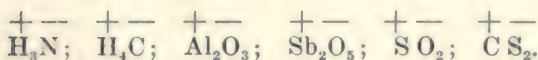
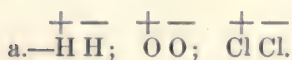
c. But one positive atom may be immediately combined with two relatively negative atoms; or,

d. One negative atom may be immediately combined with two relatively positive atoms; or,

e. One element may be partly positive and partly negative as it must be when in immediate combination with two other ele-

ments one of which is relatively of negative polarity and the other relatively of positive polarity.

The conditions described are illustrated by the following molecular formulas in which the elements are represented by their symbols, the numerals represent the numbers of component atoms, and the plus and minus signs indicate, respectively, positive and negative polarity:



In HCCl_3 , H_2CCl_2 and H_3CCl the carbon atom is negative in relation to the hydrogen but positive in relation to the chlorine; in H_4NCl the nitrogen atom is negative toward the hydrogen but positive to the chlorine; and in KCN the carbon atom is negative relatively to potassium but positive to the nitrogen.

Positive atoms carry charges of positive electricity; negative atoms carry charges of negative electricity.

11. Any given chemical compound always contains the same component elements and in the same mass proportions.

These mass proportions may in all cases be reduced to multiples of the respective atomic weights of the component elements.

Any two compounds containing the same elements but in different proportions have different properties and are therefore, different substances.

But molecules containing the same elements in the same proportions are not identical substances unless the component atoms occupy the same positions with relation to each other.

12. Molecules are the smallest individual particles of matter capable of independent existence.

The molecules of chemical elements consist of one or more atoms of the same kind. (See par. 3.)

The molecules of any chemical compound are the smallest particles into which that compound can be divided without losing the specific properties which determine its individuality. **Compound molecules** consist of two or more different kinds of atoms held together in one unbroken system of atomic linking according to their respective valences. (See par. 16, 17 and 18.)

All molecules of the same kind of matter are of the same composition and structure and have the same mass.

Two or more molecules of the same or of different kinds may be chemically combined with each other to form particles of matter of definite chemical composition and fixed least mass, but such **molecular compounds** instead of having but one unbroken system of atomic linking must be assumed to have as many independent systems of atomic linking as the number of molecules contained in each least particle of fixed composition and mass, or a separate system for each component molecule. (See par. 18 and 27).

13. The **molecular weight** of any kind of matter is the mass of its molecule. It is the sum of the weights of the component atoms.

14. Simple and definite atomic combining proportions are evident in numerous compound molecules.

When but two elements enter into a chemical compound and each atom of either element is in immediate combination with each atom of the other element the numerical proportions of the atoms of those two elements are either equal numbers or 1 to 2, 1 to 3, 1 to 4, 1 to 5, 1 to 6, 2 to 3, 2 to 5, or 2 to 7.

One atom of silver unites with one atom of bromine; one of zinc with one of oxygen; one of boron with one of nitrogen; one of oxygen with two of hydrogen; one of aluminum with three of chlorine; one of carbon with four of hydrogen; two

of arsenic with three of oxygen, or two of arsenic with five of oxygen; two of chlorine with one, two, three, five or seven of oxygen; one of nitrogen with three of hydrogen, or one of nitrogen with one or two of oxygen, or two of nitrogen with one, two, three, four or five of oxygen.

One atom of one element may hold in combination with itself one or more atoms of two or more other elements.

15. The atomic hypothesis is supported by the following facts:

a. The fixed combining proportions of the elements have been determined by analyses and syntheses of numerous compounds.

b. **All atoms have the same capacity for heat** (Law of Dulong and Petit) as demonstrated by the established fact that it requires the same amount of heat to raise the temperature of any atom of any kind one degree, the "specific heat" of each element being inversely as its atomic weight.

By **specific Heat** is meant the relative quantity of thermal energy (or heat) necessary to raise the temperature of a given mass of any substance one thermal degree.

Specific heat is expressed in units of the specific heat of water, which is taken as the standard of comparison. Thus the quantity of heat required to raise the temperature of one weight unit of water one degree, or the specific heat of water is =1. But only $\frac{31.00}{1000.00}$ as much heat or thermal energy is required to raise the temperature of the same mass or weight unit of mercury one degree, and the specific heat of mercury is, therefore, 0.0319.

The atomic weight of any element may be deduced from or verified by its specific heat, for, inasmuch as all atoms of whatever kind have the same capacity for heat, it follows that the product obtained by multiplying the atomic weight by the specific heat of the same element is a constant number. That number is found to be approximately 6.40, and is called **atomic heat**.

Thus the atomic heat of any element divided by its specific heat gives its atomic weight, the atomic heat divided by the atomic weight gives the specific heat; and the specific heat multiplied by the atomic weight gives the atomic heat.

Neumann and Regnault proved that the specific heats of **compounds** are inversely proportional to their **molecular** weights, just as the specific heats of **elements** are inversely as their **atomic** weights.

After further investigations by Regnault and others the conclusion was accepted that all atoms, free or combined, have the same capacity for heat.

The sum of the atomic heats of the atoms of any molecule is the molecular heat of the molecule. Therefore, the molecular heat of any compound divided by the number of atoms contained in its molecule must give a quotient which is the mean of the atomic heats of its component elements (or, in other words, a quotient of approximately 6.4.). Hence if the molecular heat of any substance is divided by 6.4, the quotient expresses the number of atoms contained in the molecule.

Atomic and molecular weights may therefore be deduced from or verified by the specific heats of substances.

c. The natural classification of the elements into groups according to their chemical properties, such as their polarity and valence, and according to the structure and properties of the compounds they form, confirms the atomic theory, for such a classification actually results from the arrangement of the elements in the order of their atomic weights. (See next chapter.)

d. The fixed combining proportions by weight of the component elements of compounds are explained by the atomic theory, and no other sufficient explanation thereof has yet been made.

e. The numbers expressing the respective "vapor densities" of all substances are one-half of the magnitude of the numbers expressing their molecular weights, and it, therefore, follows that the atomic weights of all elements having diatomic molecules coincide with their vapor densities, which accordingly serve to verify atomic weights.

The density of hydrogen is the unit chosen for the expression of the relative specific densities of all other gases. The specific density of hydrogen is 1, its atomic weight is 1, and its molecular weight is 2 for its molecule is diatomic.

The molecular weight of any substance is twice its vapor density.

The atomic weight of oxygen is 16 and one cubic-decimeter of it weighs 16 times as much as one cubic-decimeter of hydrogen weighs.

The atomic weight of nitrogen is 14, and the weight of 1 liter of nitrogen is 14 times the weight of 1 liter of hydrogen.

If the molecule of a given element contain but one atom, then the atomic weight of that element coincides with its molecular weight and is equal to twice the number expressing its vapor density.

As the vapor density of mercury is 100 (one cubic-decimeter of its gas weighing 100 times as much as the weight of one cubic-decimeter of hydrogen), its atomic weight is 200 and that is also its molecular weight. Hence its molecule must be monatomic.

The atomic weight of an element having tetratomic molecules (molecules containing 4 atoms) must be equal to one-half of its vapor density.

Gaseous elements combine in simple volume proportions, and the volumes of the products bear simple relations to the volumes of the factors (Gay-Lussac).

To make this fact plain to the student we will assume that one volume of hydrogen contains 10 molecules of that element. According to the hypothesis of Avogadro one (equal) volume of chlorine must contain the same number. It has been shown that one molecule of hydrogen contains at least two atoms and there are sufficient reasons for the assumption that it does not contain more than two atoms. For good reasons it is assumed that the molecules of chlorine are also diatomic. Therefore one volume of hydrogen would contain 20 atoms, and one volume of chlorine 20 atoms. When mixed and caused to unite chemically one volume of hydrogen and one volume of chlorine will form exactly two volumes of gaseous hydrogen chloride, made up of the 40 atoms of the two elements, and as each volume of gaseous hydrogen chloride must contain the same number of molecules of hydrogen chloride as one volume of hydrogen contains of hydrogen, two volumes of hydrogen chloride contains 20 molecules and each molecule must accordingly contain two atoms—one of hydrogen and one of chlorine.

For the same reasons 2 liters of hydrogen and 1 liter of oxy-

gen will produce 2 liters of water vapor (the molecules of water being triatomic); and 3 liters of hydrogen with 1 liter of nitrogen will produce 2 liters of gaseous ammonia (the molecule of ammonia being tetratomic). See par. 27.

16. Valence. The individual numerical combining value of one atom of any given element contained in a chemical compound as compared with the combining value of any other atom in chemical combination is called its valence. It is the **quantity** of the combining power of the atom as measured by the number of other atoms it can hold or be held by.

Some elements seem to have an invariable valence; others have two or more valences. But valence is evidently subject to law, even when variable, for the variations are confined within narrow limits. It is a periodic function of atomic mass and, therefore, intimately connected with the relative positions of the elements when arranged into series and groups according to the law of periodicity. (See next chapter.)

But the respective valences of the component atoms of a molecule are not readily seen from the commonly employed molecular formulas of substances composed of more than two elements, or from the commonly employed molecular formulas of compounds in which two or more atoms of the same element are in immediate combination with each other. The respective valences of the component elements of such molecules are disclosed only by graphic structural formulas showing the assumed actual connections or relative positions of the atoms. The multiple proportions of the component elements of such molecules are often far from simple.

Valence, therefore, is the number of units of atomic combining value by which any atom is held in actual combination with one or more other atoms in any given molecule. (See par. 17.)

Atoms may be united to each other not only to form strictly binary compounds (par. 10 b.), but they may form chains, clusters, rings and other groups.

17. Bonds. The term "bond" is commonly employed to express the unit of valence. It is a convenient and useful expression.

The hydrogen atom having an invariable valence of 1 is

said to have 1 bond; the oxygen atom has 2 bonds because it can hold two hydrogen atoms; the nitrogen atom when holding three hydrogen atoms in combination has 3 bonds, but when holding one oxygen atom it has 2 bonds; the carbon atom holding one oxygen atom has two bonds, but when holding two oxygen atoms it has 4 bonds, etc.

Different atoms may have different numbers of bonds, from 1 to 8, as their different valences may be any number from 1 to 8.

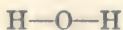
We speak of the carbon bonds, the nitrogen bonds and the bonds of other elements in discussing the structure of carbon compounds, and the conception of atomic linking (par. 18) is indispensable to intelligent study and progress in organic chemistry and must continue to be so until other means of explanation shall have been discovered. Whatever is useful and permissible in the chemistry of the carbon compounds is equally useful and permissible in all chemistry.

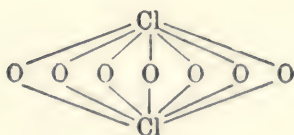
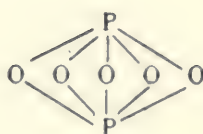
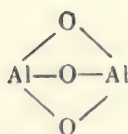
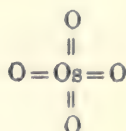
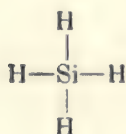
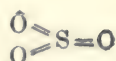
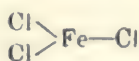
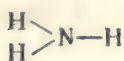
But the use of the words "bond" and "bonds" should not be permitted to convey the idea that atoms are possessed of links, ligaments, arms, or points of attachment by which they hold each other in combination. The term bond is used only in a figurative sense to represent the unit of atomic valence. Pictorially and figuratively we may accordingly represent chemical compounds by symbolic formulas showing their supposed structure, indicating the relative positions and connections of their component atoms by means of lines which stand for the units of valence.

Units of combining value according to modern views represent electric charges. (See par. 39.)

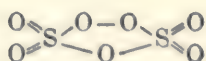
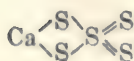
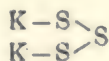
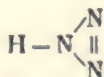
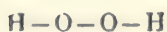
The following examples of molecular formulas show the interatomic connections or so-called bonds:

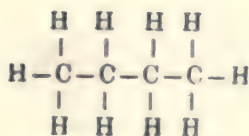
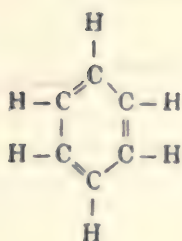
Compounds in which each atom of one element is united to each atom of the other. (Binary compounds.)



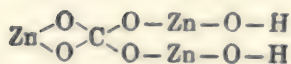
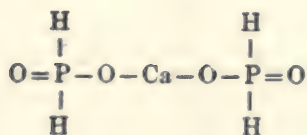
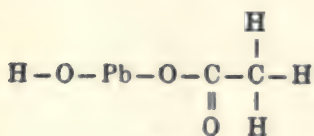
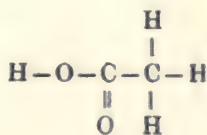
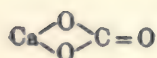
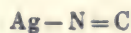
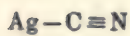
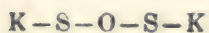


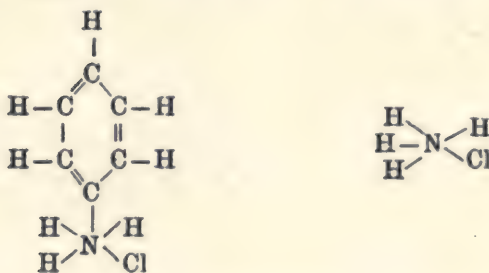
Compounds of two elements in which two or more atoms of one element are united immediately to each other:





Compounds of three or more elements.





18. The assumed mutual connection of atoms in the formation of molecules according to our conception of valence, as illustrated by the graphic structural formulas in par. 17, is called **atomic linking**.

There is but one (unbroken) system of atomic linking in any molecule.

All molecules of the same substance have the same atomic linking.

19. Each of the several valences 1, 2, 3, 4, 5, 6, 7 and 8 are exhibited in chemical compounds. Some elements have but one valence or an unchangeable valence (par. 23); other elements may have two, or three, or four, or even more than four different valences, or have a variable valence (par. 24).

No atom exhibits a valence higher than 8.

For convenience:

Atoms having a valence of 1 are called monads.

Atoms having a valence of 2 are called dyads.

Atoms having a valence of 3 are called triads.

Atoms having a valence of 4 are called tetrads.

Atoms having a valence of 5 are called pentads.

Atoms having a valence of 6 are called hexads.

Atoms having a valence of 7 are called heptads.

Atoms having a valence of 8 are called octads.

Monads are termed monovalent and have 1 bond.

Dyads are termed divalent and have 2 bonds.

Triads are termed trivalent and have 3 bonds.

Tetrads are termed tetravalent and have 4 bonds.

Pentads are termed pentavalent and have 5 bonds.

Hexads are termed hexavalent and have 6 bonds.

Heptads are termed heptavalent and have 7 bonds.

Octads are termed octovalent and have 8 bonds.

20. It follows from the definition of valence, and is rendered clearer by the representation of valence units by means of lines called bonds, that a monad atom can be directly combined by atomic linking with only one other atom since it has only one bond; a dyad having 2 bonds can be linked to one other dyad or to two monads, or to any two atoms; a triad may be united to one, two or three atoms, etc.

It is apparent, too, that the total number of bonds in any molecule must be an even number for every bond must be paired off or "tied" by another bond [of opposite polarity].

21. The **potential valences** of free elements are the valences which they may assume when they enter into actual combination.

The **actual valences** of atoms are those exhibited by them when in actual combination.

A free or uncombined atom must necessarily be regarded as having no actual valence or a valence expressed by 0.

The potential valence of a free oxygen atom is 2, but its actual valence is 0; the actual valence of oxygen becomes 2 only when it enters into combination with another element, as in H_2O .

22. Whenever the valence of any given element has been found to be the same in all of its known compounds we may and do make good use of that knowledge; the potential valence of the free element is then held to be identical with its actual valence when in combination.

23. The following elements are recognized as having a constant or invariable valence:

Monovalent elements.—The valence of H, Li, Na, K, Rb, Cs, Ag, and F is 1.

Divalent elements.—O, Be, Mg, Ca, Sr, Ba, Zn and Cd have a valence of 2.

Trivalent elements.—Al and B have a valence of 3.

Any element which in any compound has a valence higher than 3 has a variable valence.

24. **Variable valence** is exhibited by many elements. Thus, for instance, copper and mercury have a valence of 1 in one

class of their compounds but a valence of 2 in another class. Carbon has a valence of 2 in CO but of 4 in CO_2 . Phosphorus has a valence of 1, 3 or 5; sulphur, 2, 4 or 6; iodine, 1, 3, 5 or 7; nitrogen 1, 2, 3, 4 or 5; chlorine, 1, 3, 4, 5 or 7; manganese 2, 3, 4, 6 or 7.

When any element exhibits several different valences its several valences often differ by two units. Thus an element having a valence of 7 may also have either of the valences 5, 3 and 1; an element having a valence of 6 may also have either of the valences 4 or 2.

Hence the valences of some elements are represented by odd numbers only; those of other elements by even numbers only. But, as shown in the foregoing, several elements show irregular valences, odd and even.

Nitrogen which exhibits an even valence in NO and N_2O_4 (or NO_2) shows normal (odd) valences in all its other compounds, and the N of nitrosyl and nitril is trivalent in all compounds containing those compound radicals.

25. Normal valences are the valences indicated by the positions of the elements in the periodic system.

The **ruling valences** of elements are those exhibited by them in their most common and stable compounds.

The ruling valences are generally normal valences.

26. Valence can have no meaning unless it means that a free atom has no actual valence or a valence expressed by 0. It means nothing unless it means that when any two atoms are in immediate combination with each other in any molecule, elemental or compound, simple or complex, those two contiguous atoms must be held to each other by the same number of bonds from each atom. It clearly means that all the bonds of each and all of the constituent atoms of the molecule are utilized in actual combination (or "tied") so that no atom in any molecule possesses any free bond. Free or disconnected bonds are conceivable only as possessed by disconnected ions (par. 35).

Therefore, **a molecule has no valence, or its valence is 0.**

All the constituent atoms of any molecule must together have an even number of bonds.

Hence, as a purely mathematical proposition, it follows that if one-half of all the bonds or valence units by which the com-

ponent atoms of any molecule are held in chemical combination be each assigned the algebraic value of $+1$ and each of the other half of the bonds or units of valence be given the value of -1 , the algebraic sum of all these values must be 0.

A molecule composed of C, O and H can not contain an odd number of hydrogen atoms.

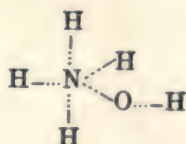
One-half of the units of valence represent charges of positive electricity. They are the valence units of relatively positive elements and may be called "positive bonds," each designated as having a combining value of $+1$.

The other half of the units of valence represent charges of negative electricity. They are the valence units of relatively negative elements and may be called "negative bonds," each designated as having a combining value of -1 .

In the molecule H_2O we have two positive bonds (those of the two hydrogen atoms) and two negative bonds (those of the oxygen atom). The sum of $+2$ and -2 is 0.

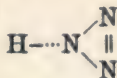
In the molecule HOOH we have again the two positive bonds of the hydrogen atoms, and two negative oxygen bonds to offset them; but the two oxygen atoms are immediately combined with each other by two other bonds one of which is positive and the other negative so that one of the oxygen atoms has an algebraic combining value of -2 while the algebraic combining value of the other oxygen atom must be expressed as 0 since it must have one positive and one negative bond. (See par. 39.)

In the molecule H_4NOH we have 5 positive hydrogen bonds and 2 negative oxygen bonds; the nitrogen atom has 4 negative bonds by which it holds four hydrogen atoms and 1 positive bond by which it is held to one of the oxygen bonds, while the second oxygen bond is united to the fifth hydrogen atom. Thus we have in this molecule 6 positive and 6 negative bonds, and $+6$ added to -6 makes the sum of 0. This is clearly shown by the structural formula



in which the positive bonds are represented by solid lines and the negative bonds by dotted lines.

In the molecule of the compound called **azoimide**, HN_3 , the algebraic sum of the valence units or bonds by which the three nitrogen atoms are held together must be 0, but an additional nitrogen bond having the value of -1 is cancelled by the value of the hydrogen bond which is $+1$. The structural formula may be represented as



27. Molecular combinations. The molecule of ferric chloride consists of one atom of iron and three atoms of chlorine, and is now represented by the molecular formula FeCl_3 . It was formerly represented by the formula Fe_2Cl_6 on the assumption that it was twice as large. Both compounds actually exist. At 1000°C . the particles of gaseous ferric chloride are FeCl_3 ; somewhat below 700° the vapor is made up of particles of $(\text{FeCl}_3)_2$.

Below 500°C . the vapor of iodine consists of diatomic molecules, I_2 ; at 1700° it consists of single atoms.

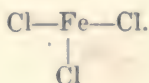
Avogadro's hypothesis, as generally stated, is that "equal volumes of all gases at the same temperature and pressure contain the same number of molecules." This form of statement necessarily leads to the conclusion that there may be more than one kind of molecules of the same substance, as, for instance, molecules of Cl and Cl_2 , I and I_2 , FeCl_3 and Fe_2Cl_6 , etc.

Chemists, however, find it necessary to assign but one molecular formula to any given substance. Thus the molecule of ferric chloride is now always written FeCl_3 . This agrees with the definition of the term molecule as given in par. 12.

Avogadro's rule should read: Equal volumes of all gases at the same temperature and pressure contain the same number of **individual particles of matter** (not necessarily molecules). See p. 155.

The **smallest** particle of ferric chloride is its true molecule. That is FeCl_3 , and this formula is in harmony with the assumption that ferric iron has a valence of $+3$ and the chlorine, as in

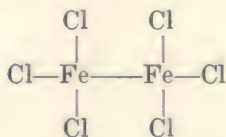
other chlorides, a valence of -1 . The atomic linking is then seen to be



The **double molecule** of ferric chloride generally represented as Fe_2Cl_6 should rather be written $(\text{FeCl}_3)_2$ because it is impossible to write any structural formula showing but one unbroken system of atomic linking in a compound of two trivalent atoms and six monovalent atoms.

Distinction should be made between least particles of matter of definite composition having but one unbroken system of atomic linking, and least particles which exhibit more than one system.

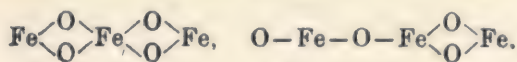
An explanation of the structure of Fe_2Cl_6 in harmony with the doctrine of valence has been made based on the assumption that ferric iron is not trivalent but tetravalent—the tetravalence of iron being in accord with the position of iron in the periodic system. The graphic structural formula given in accordance with that assumption is—



But iron is evidently trivalent in Fe_2O_3 , $\text{Fe}(\text{OH})_3$, and other ferric compounds as well as in FeCl_3 .

In the compound represented as Fe_3O_4 the iron atoms do not all have the same valence, since the total of the valence units of the four oxygen atoms is 8 and that number is not divisible by 3 into aliquot parts. Hence the formula Fe_3O_4 can not be reconciled with the conception of valence except upon the assumption that one of the iron atoms must have a valence different from that of the other two, or upon the assumption that it is a molecular combination of FeO with Fe_2O_3 , each of these molecules having its own separate system of atomic linking.

The possible single systems of atomic linking are

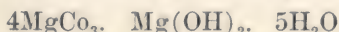


and $\text{O}=\text{Fe}-\text{O}-\text{Fe}-\text{O}-\text{Fe}=\text{O}$.

[The last would be FeFe_2O_4 , "ferrous ferrite," corresponding to MgAl_2O_4 .]

The compound consisting of one molecule of barium chloride and two molecules of water must be written $\text{BaCl}_2 + 2\text{H}_2\text{O}$. It is a combination of three distinct molecules each having its own independent system of atomic linking; yet it is a compound of definite chemical composition and each least particle of it is $\text{BaCl}_2 + 2\text{H}_2\text{O}$.

The compound represented by the expression



is by that statement recognized as a combination of 4 molecules of MgCO_3 with 1 molecule of $\text{Mg}(\text{OH})_2$ and 5 molecules of water. According to that expression it has 10 separate systems of atomic linking. Without the water it may, however, be represented as a single interatomic system.

All hydrates (par. 54) are molecular combinations, including substances containing what has been called "water of crystallization."

Of the interesting compounds the structure of which exhibits more than one system of atomic linking we may mention by way of illustration the ferro-cyanides, ferri-cyanides, fluosilicates and chloroplatinates. But the formula $\text{K}_4\text{Fe}(\text{CN})_6$ can be split up into $4\text{KCN} + \text{Fe}(\text{CN})_2$; K_2SiF_6 into $2\text{KF} + \text{SiF}_4$; and K_2PtCl_6 into $2\text{KCl} + \text{PtCl}_4$.

28. Unsaturated molecules are groups of atoms which, like molecules, are capable of at least temporary individual existence but in which one of the component atoms exercises an actual valence lower than its highest normal potential valence.

The compound NO is capable of temporary existence. The normal valences of N are odd, being 1, 3 or 5. But the actual valence of the N in NO is clearly 2. Hence NO is an unsaturated molecule. It is recognized as a commonly occurring compound radical (par. 29) under the name of nitrosyl (see par. 81) which is uniformly monovalent.

29. Compound radicals are distinct groups of atoms recognized as occurring in molecules of which they constitute characteristic components.

Compound radicals are held together, and joined to other atoms or atomic groups in the molecules in which they occur, in conformity to the accepted doctrine of atomic valence.

The group HO or OH is a compound radical. It is not known to be capable of independent existence, but is common to all hydroxides and several other classes of compounds. It is called **hydroxyl**. It is a compound radical because the atomic valence of oxygen is twice as great as that of hydrogen so that the atom of oxygen in the OH can be further united to some other atom. The molecules HOH, KOH, HOCl, H_3COH , HONO_2 , $\text{Ca}(\text{OH})_2$, and $\text{Fe}(\text{OH})_3$ are examples of hydroxyl compounds.

All the compound ions of acids, bases and salts are compound radicals.

The compound radical OH is a negative radical because the valence by which it is united to other atoms or atomic groups is one-half of that of the negative element oxygen (par. 39).

NO_3 is the compound ion or radical of all the common nitrates; SO_4 is the characteristic compound radical of the common sulphates; CO_3 that of the carbonates; PO_4 that of the common phosphates.

Other examples of common compound radicals are: CO, called carbonyl; NO, called nitrosyl; OBi, called bismuthyl; NH_2 , which is contained in all amido-compounds; CH_3 , called methyl, and many other hydrocarbon radicals; etc.

30. The hydrogen valence of any element is expressed by the number of hydrogen atoms which a single atom of that element holds in immediate combination when united to hydrogen alone.

Thus the hydrogen valence of chlorine is 1 because one single chlorine atom can hold only one hydrogen atom in combination; the hydrogen valence of oxygen is 2 because one single atom of oxygen is known to hold in combination with itself neither more nor less than two hydrogen atoms; the hydrogen valence of nitrogen is 3 because one single atom of nitrogen is known to hold in combination with itself neither

more nor less than three hydrogen atoms; and the hydrogen valence of carbon is 4 because the only substance known which is composed of carbon and hydrogen and contains only one carbon atom, contains four hydrogen atoms.

No single atom of any kind is known to be able to hold in combination with itself more than four hydrogen atoms.

Metals rarely combine with hydrogen and such hydrides of the metals as are known either resemble alloys in that they exhibit metallic physical properties, or they are very unstable.

Non-metallic elements all combine with hydrogen, and their binary hydrogen compounds are gaseous at ordinary temperatures except water.

It is a significant fact that the hydrogen valence of any given element is a fixed number, or that, in other words, no element has more than one hydrogen valence.

The hydrogen valence of carbon and silicon is invariably 4; that of any element of the nitrogen group is invariably 3; that of oxygen or of any element in the sulphur group is 2; and that of any halogen is 1.

The hydrogen standard for the measurement of valence has, therefore, a specific value notwithstanding its limited range.

The actual valence of any wholly negative element in any compound is its hydrogen valence.

Hydrogen valences are conclusively established by the structure of strictly binary compounds.

That the hydrogen valence of any element must be exhibited by the compound which a single atom of that element forms with hydrogen alone is evident from the fact that the valence of hydrogen is 1.

31. The **oxygen valence** of any element is its capacity to hold oxygen in combination with itself. The hydrogen valence of oxygen is 2 because one oxygen atom can hold two hydrogen atoms. The oxygen valence of hydrogen is 1 because the valence of the oxygen atom is evidently twice that of the hydrogen atom in the only compound of hydrogen and oxygen containing only one atom of one of those elements (water).

No single atom of any kind is known to be able to hold in combination with itself more than four oxygen atoms when combined with oxygen alone. Two compounds are known com-

posed of four oxygen atoms united to one other atom (OsO_4 and RuO_4).

The highest valence attained by any element is its maximum oxygen valence, and, as the valence of oxygen is twice as great as the valence of hydrogen, it follows that the highest valence possible to any atom is 8.

The various oxygen valences possible are 1, 2, 3, 4, 5, 6, 7 and 8.

Designating oxygen as O and the element combined with it as R we may represent oxygen valences by the following general formulas in which the numbers of atoms of oxygen express those valences:



Two atoms of R are written in these formulas because one oxygen atom can hold two hydrogen atoms. The general formulas R_2O_2 , R_2O_4 , R_2O_6 and R_2O_8 exhibit **proportional numbers** of the atoms of R and O; the **actual numbers** are seen in the formulas RO , RO_2 , RO_3 and RO_4 , respectively.

To find the oxygen valence of any element in any one of its oxides (in which each atom of one of the elements is directly united to each atom of the other) **divide twice the number of oxygen atoms contained in one molecule of the oxide by the number of atoms of the other element.**

The valence of the R in R_2O is 1; in R_2O_2 or RO it is 2; etc.

Nearly all elements combine directly with oxygen and valence is accordingly much more frequently measured by the oxygen standard than by hydrogen.

But the normal oxygen valences of elements are known from their hydroxides and from the salts formed by those hydroxides, rather than from their oxides.

32. Neither hydrogen valences nor oxygen valences can be determined from compounds containing two or more atoms of the same element connected immediately to each other, as, for instance, from HN_3 , HOOH , H_2NNH_2 , S_2O_7 , or CaSS_4 .

33. Valence as commonly defined is expressed by a number assumed to refer to the specific numerical combining value of the hydrogen atom as the unit. The valence of any other atom

is usually said to be "the number of hydrogen atoms which it can hold in combination with itself or which it can replace in any compound." But this definition is subject to the following objections:

a. Less than one-fourth of the elements are known to combine directly with hydrogen.

b. Apparently no single atom of any kind can hold more than four hydrogen atoms, which fact limits the valence directly measurable by hydrogen to four units whereas the maximum valence of a large number of elements exceeds 4.

c. The number of hydrogen atoms which any other atom can "replace" in any given molecule does not decide the question of its valence in molecules in which it can not be said to replace that element. Elements with valences above 4 form compounds in which they neither combine with nor replace hydrogen.

We have seen (par. 30) that the hydrogen valence of any given element is unchangeable, while the oxygen valence of an element may vary (par. 31).

Hydrogen valences and oxygen valences are intimately related and may in a manner be arithmetically expressed by identical numbers, as is commonly done, but they are widely different in their significance as well as in their range, and when any given element forms compounds with hydrogen as well as compounds with oxygen its hydrogen valence is limited by its oxygen valence, and the reverse, so that it is evident that **the hydrogen standard and the oxygen standard for the measurement of valence are not identical or interchangeable but complementary.** (See par. 34.)

Units of hydrogen valence represent charges of negative electricity, whereas units of oxygen valence represent charges of positive electricity.

34. When the number of hydrogen atoms which a single atom of any non-metallic element can hold in immediate combination with itself (in other words, the hydrogen valence of that element) is added to the maximum valence which the same element can attain in combination with oxygen, the sum of these two valences is 8, except in the cases of B and Br.

Thus the valence of C in H_4C added to its valence in CO_2 and in all carbonates is 8; the sum of the valence of N in H_3N and its valence in N_2O_5 and in all nitrates is 8; the sum of the valence of the S in H_2S and its valence in SO_3 and in all kinds of sulphates is 8; and the valence of Cl in HCl added to its valence in the perchlorates makes the sum of 8.

When four oxygen atoms are directly combined by all of their valence with any one other atom this atom can not at the same time hold any third element in combination. But if four oxygen atoms are contained in one molecule of any inorganic acid containing no hydrogen except that united to the oxygen, then the number of hydrogen atoms in that molecule must be that expressed by the hydrogen valence of the acidic element* and no other number.

This is shown in the following table:

Hydrogen Compound:	Hydroxyl Acids.	Hydrogen Valence of the Element.	Oxygen Valence of the Element.	Sum of the two Valences.
HCl	HClO_4	1	7	8
HI	HIO_4	1	7	8
H_2S	H_2SO_4	2	6	8
H_2Se	H_2SeO_4	2	6	8
H_2Te	H_2TeO_4	2	6	8
H_3N	H_3NO_4	3	5	8
H_3P	H_3PO_4	3	5	8
H_3As	H_3AsO_4	3	5	8
H_3Sb	H_3SbO_4	3	5	8
H_4C	H_4CO_4	4	4	8
H_4Si	H_4SiO_4	4	4	8

Salts of all these hydroxyl acids are known.

The valence of the acidic element in each acid is its maximum oxygen valence.

From these comparisons it is evident that the oxygen valences of the elements are limited by their hydrogen valences and vice versa. An element which does not combine with hydrogen and has no hydrogen valence may have an oxygen

*By the acidic element is meant the third element, or that combined with the hydroxyl.

valence as high as 8. Any element which in any of its compounds has a valence of 8 can in no case be a negative element. A hydrogen valence of 1 limits the highest possible oxygen valence to 7; a hydrogen valence of 2 makes the highest possible oxygen valence 6; an element having a hydrogen valence of 3 can never attain a higher valence than 5; and when the hydrogen valence is 4 the oxygen valence can not exceed 4.

As valence is commonly expressed we say that the highest valence exhibited by carbon is 4 and its lowest valence 2, showing a difference of two units; the highest valence of nitrogen is 5 and the lowest 1, a difference of four units; the highest valence of sulphur is 6 and the lowest 2, again a difference of 4 units; the highest valence of chlorine is 7 and the lowest 1, a difference of six units. But if the numbers expressing hydrogen valence be treated as minus values and those expressing oxygen valence as plus values, as should always be done (par. 39), we shall then find that the difference between the highest and the lowest combining values are invariably 8 units in the cases of C, Si, N, P, As, Sb, S, Se, Te, Cl, and I. [Oxygen and fluorine have no oxygen valences and perbromates are unknown.]

Evidently then, the hydrogen standard and the oxygen standard are not identical or interchangeable but complementary. The combining value of C then has a range of from -4 to $+4$; the range of combining value of N is from -3 to $+5$; that of S from -2 to $+6$; and that of Cl from -1 to $+7$.

Comparisons of the known combining values of representative non-metallic elements as commonly expressed (without the use of plus and minus signs) and as expressed algebraically are shown in the following table of compounds formed by oxygen or hydrogen, or both, with a third element:

Compounds.	Valence of the Third Element.	
	As Commonly Expressed. (The number of Bonds Added Arithmetically).	Sums of Positive and Negative Bonds Counted Algebraically.
H_2CO_3	4	+4
HCOOH	2	+2
CO	2	+2
C	0	0
H_3COH	2	-2
H_4C	4	-4
HNO_3	5	+5
HNO_2	3	+3
HNO	1	+1
N	0	0
H_3N	3	-3
H_4NOH	5	-3
H_3PO_4	5	+5
H_3PHO_3	5	+3
HPH_2O_2	5	+1
P	0	0
H_3P	3	-3
H_2SO_4	6	+6
H_2SO_3	4	+4
H_2SO_2	2	+2
S	0	0
H_2S	2	-2
HClO_4	7	+7
HClO_3	5	+5
HClO_2	3	+3
HClO	1	+1
Cl	0	0
HCl	1	-1

35. The modern theory of **ionization** teaches that a large number of chemical compounds when dissolved in water split up into two parts called "ions," and that one of these ions is charged with positive electricity and the other with negative electricity. The ion charged with positive electricity is called the **positive** ion or **cation**, and the ion charged with negative electricity is called the **negative** ion or **anion**. The extent of this dissociation of molecules into ions by solution depends upon the composition of the molecule and the degree of dilution of the solution.

When a galvanic current passes through the solution the positive ions move toward the negative pole of the battery called the **cathode**, and the negative ions travel to the positive pole called the **anode**.

The ions of acids, bases and salts are independent atoms or atomic groups.

When a compound consisting of but two atoms is ionized the ions are free atoms, one positive and the other negative. When the ionized compound is composed of three elements it follows that one of the ions must consist of one element and the other must be a **compound ion** composed of the other two elements.

Other compounds split up by ionization may form two compound ions, one positive and the other negative.

These facts prove that chemical combining energy is either electricity itself or closely related to it.

The combining energy by which the component atoms of compound ions are held together must be the same as that which unites positive ions and negative ions into molecules.

Positive ions and negative ions may be regarded as possessing free bonds. The free bonds of the positive ions are the bonds of **positive elements**, and the free bonds of negative ions are the bonds of **negative elements** (par. 37).

When a molecule composed of a metal and a non-metallic element is ionized, the metal constitutes the positive ion and the non-metallic element is the negative ion. Metals are always positive elements in relation to the non-metallic elements.

When a basic metallic hydroxide (par 67) is ionized the metal constitutes the positive ion and the hydroxyl (OH) the negative ion.

When an acidic hydroxide or hydroxyl acid (par. 61) is ionized the positive ion is hydrogen.

When an inorganic oxygen salt is ionized the basic metal is the positive ion.

The ionization of potassium chloride, water, hypochlorous acid, potassium hydroxide, and potassium hypochlorite may be represented as follows:

Molecular formula.	Positive ion.	Negative ion.
KCl	K	Cl
HOH	H	OH
HOCl	H	OCl
KOH	K	OH
KOCl	K	OCl

But diatomic elemental molecules also divide into two ions, one positive and the other negative.

A molecule of chlorine consists of two atoms, one a positive chlorine atom and the other a negative chlorine atom.

Consistency equally demands that a molecule of hydrogen be regarded as composed of one positive hydrogen atom and one negative hydrogen atom, and that a molecule of oxygen be regarded as containing one positive oxygen atom and one negative oxygen atom. [Proof of this is presented in the Chapter on Oxidation and Reduction.]

Only soluble substances are capable of ionization. But as all water-soluble acids which have been ionized yield hydrogen ions, it is assumed that the cations of all acids must be hydrogen atoms; as all water-soluble bases which have been ionized yield hydroxidions (OH) it is assumed that the anions of all basic hydroxides must be hydroxyl groups; and as all water-soluble metallic salts which have been ionized yield cations consisting of the metals, it is assumed that the cations of all metallic salts are their basic metallic elements.

When water undergoes ionization it yields both hydrogen ions and hydroxyl ions; the cation of acids and the anion of bases. Hence water is neither an acid nor a base, but constitutes the dividing line between them.

36. **Hydrogen and oxygen are relatively of opposite chemical polarities.** Hydrogen is a **positive element** as compared with all other non-metallic elements. [Some chemists class it with the metals.] Oxygen is a negative element as compared with all other elements metallic and non-metallic.

Water is decomposed by the galvanic current into its component elements, hydrogen and oxygen. The hydrogen collects at the negative pole of the battery and the oxygen at the positive pole. Hence, the hydrogen is designated as the positive element of water, and oxygen as its negative element.

Many compounds dissolved in water can be split into two parts by the galvanic current. The electrolytic dissociation thus effected agrees with the results of ionization (par. 35).

Carbon and nitrogen form basic atomic groups or radicals with hydrogen, but acidic groups or radicals with oxygen.

The groups CH_3 , C_2H_5 , C_6H_5 , C_3H_5 and other hydrocarbon radicals form alcohols analogous to the inorganic basic hydroxides and perform basic functions in the formation of the salts called esters. But the carbonyl group CO is an essential characteristic atomic group which in combination with hydroxyl is contained in every organic acid.

The compound called ammonia, H_3N , has decidedly alkaline properties, but the oxides of nitrogen are, on the contrary, acidic.

In the chemistry of the carbon compounds oxidation may mean either combination with oxygen or the removal of hydrogen, and reduction is the opposite of oxidation and may mean either combination with hydrogen or the splitting off of oxygen. This is because hydrogen is a positive and oxygen a negative element. (See Chapter on Oxidation and Reduction.)

The most decidedly pronounced energetic positive elements are the alkali metals, Cs, Rb, K, Na and Li, and the alkaline-earth metals, Ba, Sr, and Ca. They decompose water by entering into immediate combination with its negative element, the oxygen.

The most decidedly pronounced energetic negative elements are the halogens, F, Cl, Br and I. They decompose water by entering into immediate combination with its positive element, the hydrogen.

37. Positive and Negative Elements.—The employment of the terms “positive” and “negative” in connection with the chemical elements and with ions (par. 35) and radicals (par. 29) is well-nigh universal. They are convenient terms used to express certain recognized general properties. Their use has been objected to chiefly because of the absence of any uniform and readily applicable rule by which positive elements and negative elements may be distinguished from each other in molecules. But such a rule is furnished by the law of periodicity, as will now be shown.

All metals are positive elements. All elements in immediate combination with metals are, then, negative elements.

Hydrogen is a positive element, whenever combined with any other non-metallic element.

Oxygen and fluorine are invariably negative elements in the compounds they form with any other elements, and any element when combined with oxygen or fluorine is then positive.

The respective chemical polarities of the elements

Cl, Br, I, S, Se, Te, N, P, As, Sb, C and Si

are determined by their connections, or, in other words, by the elements with which they are in immediate combination, and by their relative positions in the periodic system.

The terms positive and negative as applied to the chemical elements are relative terms, for the same element may be positive in one compound and negative in another. Thus chlorine is a positive element when in combination with oxygen, but a negative element when in combination with any other element with which it is known to form any compound. (It is hypothetically positive toward fluorine.)

As placed in a row in this paragraph any one of the twelve elements therein named by their symbols is a positive element when in combination with any element to its left but a negative element when in combination with any element to its right.

It will be seen that the order in which these twelve non-metallic elements are here placed is governed by their relative positions in the periodic system; in other words by their rela-

tive atomic weights. In the periodic table they are arranged as follows:

C	N	O	F
Si	P	S	Cl
	As	Se	Br
	Sb	Te	I

They are positive or negative in their relations to each other according to this rule:

Of the non-metallic elements in the table arranged according to the law of periodicity any element to the left is a positive element in its relation to any element to the right, and any element below is a positive element in its relation to any element above it.

Of any two elements in the same period (or horizontal row) in either the first half or the second half of the periodic table (p. 191 next chapter) that which has a smaller atomic mass is the positive element when the two are in immediate combination.

Of any two elements belonging to the same group (vertical column) that which has the greater atomic mass is the positive element when the two are immediately combined.

The atomic combining values of negative elements are fixed and are identical with their hydrogen valences (par. 30).

The atomic combining values of positive elements are their oxygen valences (par. 31).

38. The relative intensity of the chemical energy of positive elements belonging to the same family is in direct ratio as their respective atomic weights.

The relative intensity of the chemical energy of negative elements of the same family is in inverse ratio as their respective atomic weights.

These conditions are apparent in the families of the most pronouncedly positive elements—the metals of the alkalis and of the alkaline earths—and the most pronouncedly negative elements called the halogens.

In the following table the elements referred to are given together with their atomic weights:

Alkali Metals.	At. Wt.	Alkaline-earth Metals.	At. Wt.	Halogens.	At. Wt.
Lithium	7	Beryllium	9	Fluorine	19
Sodium	23	Magnesium	24	Chlorine	35.4
Potassium	39	Calcium	40	Bromine	80
Rubidium	85.5	Strontium	87.5	Iodine	126.5
Cæsium	133	Barium	137.5		

Of the alkali metals cæsium is the most decidedly positive and its hydroxide is the "strongest" of the alkalies, while lithium forms the feeblest of the true alkalies.

Of the alkaline-earth metals barium forms the most decidedly alkaline hydroxide and is the strongest basic element, and beryllium is the most feeble.

Of the halogens fluorine displays the most intense energy, chlorine next, and iodine is the least energetic.

But when the elements of the halogen group are in combination with oxygen, and consequently are of positive polarity, the periodates are more stable compounds than the perchlorates, the iodates are more stable than the bromates, and the bromates more stable than the chlorates, while fluorine forms no known compound with oxygen. (See also par. 9.)

In the periodic table on p. 191 the negative elements are immediately to the left and the alkali metals and alkaline-earth metals to the right, of the recently discovered gaseous elements of the atmosphere (of which no compounds are known) which occupy the center of the table.

39. A true and full expression of **atomic combining value** is possible only by the use of terms which indicate both the **kind** and the **amount** of the chemical combining power referred to.

The true combining value of any atom is the algebraic sum of its positive and negative bonds.

The combining power of positive elements differs as to its **kind** from the combining power of negative elements, as positive electricity differs from negative electricity.

The **amount** of the atomic combining power of a positive element is measured by the amount of the atomic combining power of a negative element which it offsets in actual combination. Thus the atomic combining power of hydrogen is measured by the amount of the combining power of oxygen which it offsets. Conversely, the combining power of a negative element is expressed by its capacity to offset that of a positive element.

The amount of combining power of one oxygen atom offsets that of two hydrogen atoms. That of one hydrogen atom offsets one-half of the combining power of an oxygen atom.

The combining power of **negative chlorine** is that required to offset that of one hydrogen atom, for one chlorine atom can hold only one hydrogen atom. The combining power of **positive chlorine** is the amount required to offset the combining power of oxygen by which it is held in combination, for chlorine is a positive element in relation to oxygen; it may be +1, +2, +3, +5, or +7.

As the plus sign (+) is employed to designate positive electricity and the minus sign (—) to designate negative electricity, and the plus and minus signs, respectively, to distinguish between positive and negative ions, these signs are with equal propriety used to distinguish between the two opposite kinds of combining power of positive and negative elements, for the valence units of positive elements represent charges of positive electricity and the valence units of negative elements represent charges of negative electricity.

By this method we may assign to any given relatively negative element one of the atomic combining values expressed by —4, —3, —2, and —1, and to any relatively positive element one of the atomic combining values expressed by +1, +2, +3, +4, +5, +6, +7, and +8.

We will further find that by this algebraic method of expression of atomic combining values we must assign the value of 0 to any atom which is united by one-half of its combining power to a relatively positive element and by the other half of its combining power to a relatively negative element, and that the combining value of any free or uncombined atom as well as of any molecule must be expressed by 0.

Atoms whose bonds are all negative have a fixed combining

value. Only atoms having positive bonds may have more than one combining value.

Elements exhibiting atomic combining values expressed as minus quantities never perform basic or acidic functions in either oxygen salts or thio-salts; metallic elements performing basic functions in those compounds have combining values of from $+1$ to $+4$; and the metallic elements performing acidic functions have higher combining values, up to $+7$.

Any number of units of atomic combining power gained by one or more atoms in any chemical reaction are offset by a corresponding loss by one or more other atoms. A change in the combining value of any atom from $+2$ to $+6$ is a gain of 4 units; but a change from -2 to $+6$ is a gain of 8 units. A change from 0 to $+3$ is a gain of 3 units, and a change from 0 to -3 is a loss of 3 units. The quantity of oxidizing agent or of reducing agent required to effect changes of combining value is thus directly indicated by their respective algebraic combining numbers, for oxidizing agents and reducing agents are not molecules but atoms, and oxidation and reduction are transfers of units of combining value, or transfers of electric charges.

True atomic combining values may for convenience be called the algebraic combining numbers of atoms, or algebraic combining values.

40. We have stated that positive and negative elements respectively may be identified in their compounds with the aid of the Periodic Law (par. 37).

The actual true combining values of the component atoms of any molecule can accordingly be readily determined because elements of exclusively negative polarity can have only one combining value, so that the combining values of positive atoms may be known from the fixed combining values of the negative atoms with which they are in immediate combination.

As the combining values of compound radicals are also constant (par. 29) we may know the combining values of positive elements in immediate combination with negative compound radicals. Thus we can see at a glance that the algebraic combining number of the iron in $\text{Fe}(\text{NO}_3)_2$ is 2, while in $\text{Fe}(\text{NO}_3)_3$ it must be 3, for the combining value of the group NO_3 is always -1 .

41. The structure, nomenclature and classification of chemical compounds are directly dependent upon the true combining values of their component atoms and upon their interatomic linking.

Iodine exercising its oxygen valences may combine with either Br, Cl or F, which then have a combining value of -1 ; but we can have no iodide of either bromine, chlorine or fluorine. There can be only one iodine atom in any compound formed by that element with either Br, Cl or F.

In the compound CaS the combining value of the Ca is $+2$ and that of the S is -2 which is the combining value of the sulphur in all sulphides.

In the molecule commonly written K_2S_3 it is evident that the sum of the combining values of the three sulphur atoms together must be -2 because the sum of the combining values of the two potassium atoms is $+2$; hence the sulphur atoms can not all have the same value, they can not each have a value of -2 , and the compound can not be a sulphide. It is, in fact, potassium hypo-thio-sulphite, the structure of which is $\text{K} \cdots \text{S} \cdots \text{S} \cdots \text{S} \cdots \text{K}$, showing that one of the sulphur atoms—the acidic sulphur—has a combining value of $+2$ while the value of each of the other sulphur atoms is -2 . This compound is analogous to K_2SO_2 and its molecular formula should be written K_2SS_2 , or $(\text{KS})_2\text{S}$, instead of K_2S_3 ; it differs from K_2SO_2 in that the linking element (par. 56) is sulphur instead of oxygen. Only one of the sulphur atoms forms copper sulphides when a solution containing the K_2SS_2 is precipitated with CuSO_4 , the other two sulphur atoms falling as free sulphur, for as the total value of all three sulphur atoms is -2 and one of them forms CuS in which it has that value, the other two sulphur atoms must together have a value of 0, the sum of $+2$ and -2 .

It is evident at a glance that the molecule commonly written CaS_5 and called "calcium pentasulphide" can not be a sulphide because Ca has an invariable combining value of $+2$ and the combining value of the sulphur of all sulphides is -2 . It is evident further that the algebraic sum of the combining values of all the five sulphur atoms together must be -2 because the sum of all the bonds of any molecule must be 0. The compound must, therefore, be calcium tetrathiosulphate or CaSS_4 corresponding to CaSO_4 . The acidic sulphur atom in it has a value of $+6$ and the other four sulphur atoms, which exercise the functions performed by the oxygen in CaSO_4 , have a value of -2 each. Hence the algebraic sum of the combining values of all the sulphur atoms together is in fact -2 .

That the relative positions of the component atoms in a molecule determine the identity of any compound is clearly shown by the radical differences between KNC and KCN . The compound KNC is potassium isocyanide, and KCN is potassium cyanide. The two have very different properties; they are, in other words, different substances. Their graphic structural formulas are:

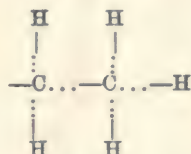


Carbon is nearly always a tetrad; but it can not be so in KNC because that would lead to the structure $K \cdots N \equiv C$, which would assign to the N an algebraic combining number of -5 . Nitrogen can not have such a combining value because its maximum algebraic combining number is $+5$ so that its lowest value must be -3 . (See par. 34.) The difference between the highest and lowest combining values of any element never exceeds 8 units. Moreover, the lowest algebraic combining value known to any atom is -4 .

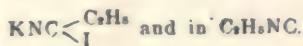
Carbon is a negative element in relation to K but a positive element in relation to N (See par. 37). Hence the C in KCN must be considered as having one negative bond holding the K and three positive bonds holding the N, so that its algebraic combining value is $+2$, the sum of -1 and $+3$.

The respective algebraic combining values of each of the component atoms are, therefore, the same in KCN as in KNC, but the valence of the C is 2 in KNC but 4 in KCN.

The compound radical C_2H_5 (ethyl) is



In $KNC \leq C_2H_5$ the first carbon atom has four bonds but its algebraic combining number is still the same as in KNC and KCN ($+2$) because the bond by which it holds the group C_2H_5 is a negative bond and that by which it holds the iodine is a positive bond. The carbon bond of the C_2H_5 by which it unites with relatively negative elements and atomic groups is a positive bond; it is a positive bond in



When hydrogen and chlorine combine with each other H is the positive and Cl the negative element. To this statement the objection might be raised that the hydrogen atoms of hydrocarbons can be replaced by chlorine which fact is said to be sufficient proof that H and Cl are mutually interchangeable and therefore can not be of opposite qualities. But positive elements and negative elements often replace each other. When, however, a positive element is replaced by a negative one, or the reverse, the new compound differs radically from the original in its general character. The hydrocarbons differ decidedly from their halogen derivatives.

If positive elements and negative elements are recognized at all, then zinc is positive. Iodine is the negative element in every iodide. But Zn and I can both enter into combination with C and can replace each others. Zinc is combined with the carbon atoms in $\text{Zn}(\text{CH}_3)_2$, and this compound is produced by the action of the metal on methyl iodide.

When the hydrogen of an organic compound is replaced by Cl or any other element it makes a difference which atomic group in the molecule is changed by the substitution. Trichloroacetic acid is referred to as an instance in which hydrogen atoms are replaced by chlorine without causing any radical change in the general character of the compound; but $\text{H}_3\text{C}.\text{CO}.\text{OH}$ and $\text{Cl}_3\text{C}.\text{CO}.\text{OH}$ are both acids because they both contain $\text{CO}.\text{OH}$ held by a carbon bond.

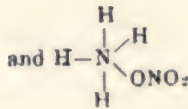
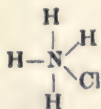
A relatively positive atom can be held in combination only by a relatively negative atom. It follows, therefore, that when any atom exchanges a positive element for a negative one or *vice versa* its own polarity must be to that extent reversed.

The combining value of the C in H_4C must be -4 ; in CCl_4 it is $+4$; in H_3CCl it is -2 ; in H_2CCl_2 it is 0; and in HCCl_3 it is $+2$. When these combining numbers are recognized it is easy to explain the reactions by which the chlorine derivatives of methane are formed, on the principle that gain and loss of combining values always offset each other unit for unit.

Phosphoric, phosphorous and hypophosphorous compounds may be distinguished from each other not by the sums of the phosphorus bonds counted arithmetically but by their sums counted algebraically. The P in HOPH_2O has 5 bonds but two of them are to be counted as minus-units because they hold two hydrogen atoms while the other three must be counted as plus-units because united to oxygen; hence the algebraic combining number of that P is $+1$. The P in $(\text{HO})_2\text{PHO}$ has 5 bonds counted arithmetically, but one of them holds a hydrogen atom, so that the algebraic combining number of this P is $+3$. The P in any phosphoric acid also has 5 bonds but its algebraic combining number is $+5$ because it is united by all of its bonds to oxygen.

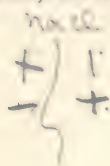
The N in H_3N has three bonds and its algebraic combining number is -3 . In H_4NCl the N has five bonds, but its algebraic combining number is the same as in H_3N , for the nitrogen bonds holding the hydrogen are negative bonds and the bond holding the chlorine must be a positive bond.

The graphic structural formulas



show that when ammonia forms ammonium chloride with HCl or am-

monium nitrate with HONO_2 the nitrogen atom of the ammonia acquires two additional bonds or units of valence, one positive and the other negative. Its algebraic combining value remains unaltered. This explains why it is that when alkaloids and derivatives of ammonia form salts with the acids no water is formed. There is no sulphuric acid in the sulphate of any alkaloid; the N of the alkaloid separates the hydrogen of the acid from the group SO_4 just as the N of ammonia does in forming $(\text{H}_4\text{N})_2\text{O}_2\text{SO}_2$ in which we can see there is no $(\text{HO})_2\text{SO}_2$.



CHAPTER II.

THE PERIODIC SYSTEM.

42. The classification of the chemical elements into natural divisions and groups is attended with difficulty because the properties of one group merge into those of other groups.

Their division into metals and non-metals is convenient, but several elements possessing the characteristic physical properties of metals in a high degree (as, for instance, tin and antimony) do not possess in a marked degree the chemical properties generally characteristic of metals, but instead resemble the non-metallic elements in important respects. Metallic elements generally perform the basic function in the formation of salts while the non-metallic elements perform the acidic function. But tin and antimony are very feebly basic, antimony forms several salts in which it performs the acidic function, and boron, which is best known from the borates and which does not possess the physical properties of the metals, seems to form a phosphate, BPO_4 .

A general division of the metallic elements into "light metals" and "heavy metals" carries with it some advantages; the light metals are, for instance, more pronouncedly basic than the heavy metals.

Certain families of elements are universally recognized as exhibiting well defined family traits and were so recognized long before the periodic system was thought of. The halogens (F, Cl, Br and I), the sulphur family (S, Se and Te), the alkali metals (Li, Na, K, Rb and Cs), the calcium family (Ca, Sr and Ba), illustrate this fact. Less definite groupings, like that of the "noble metals" were also employed for purposes of classification.

But the most natural and rational system of classification known is the so-called **Periodic System**, which is based upon the recurrence of striking similarities of chemical behavior coin-

cident with definite periods of increasing or decreasing atomic mass.

43. The English chemist Newlands appears to have been the first to observe some decided evidences of a connection between the atomic weights and chemical properties of the elements. He arranged the elements having atomic weights ranging from 7 to 35.4 with the following striking results:

Li	Be	B	C	N	O	F
7	9	11	12	14	16	19

Na	Mg	Al	Si	P	S	Cl
23	24.2	27	28.4	31	32	35.4

These two "short periods" of seven elements each exhibit ruling valences of 1, 2, 3, 4, 3, 2, and 1 in regular order. No other elements were then known whose atomic masses lie between 7 and 35.4. The only element since discovered whose atomic mass is within that range is Neon. Each of the short periods shown begins with an alkali metal and ends with a halogen.

In 1868 the Russian chemist Mendeleyev and the German chemist Lothar Meyer, independently of each other, published tables of the elements arranged in periods in the order of their atomic weights to show that a classification of them into natural groups or families results from such an arrangement.

The periodicity of the recurrence of similarities of valence and functions evidently obeys a natural law called the **Periodic Law**.

The statement of facts is usually formulated as follows:

"The properties of the elements are periodic functions of their atomic weights."

The periodic system is intensely interesting, suggestive and helpful, and brings out unmistakably the fact that the atomic mass and properties are the attributes of the individuality of each element.

44. There are many vacant spaces in all tables of the periodic system. The elements Praseodymium (140), Neodymium (143), Samarium (150), Gadolinium (157), Terbium (160), Erbium (166), and Thulium (171) have atomic weights between those of Cerium (139) and Ytterbium (173). The recently discovered elements Helium (4), Neon (20), Argon (40?), Krypton (82), and Xenon (128) can be seen to constitute a new group not provided for in the earlier tables. They belong between the halogens and the alkali metals.

One table arranging the elements into natural groups according to their properties and constructed consistently with the order of their increasing atomic weights is given on p. 188. In this table the numbers beneath the atomic weights are the atomic volumes—the quotients obtained by dividing the atomic weights by the specific densities of the elements in their solid state. In this table there are ten blank spaces between Be and B and between Mg and Al, and it seems impossible that so many elements can exist having atomic weights between 9 and 11 and between 27 and 28.4. But my object was to avoid as far as practicable the separation from each other of elements which clearly belong to one family. Lithium and sodium belong in the same family with potassium and the other alkali metals; Be and Mg belong to the same group as Ca, Sr and Ba; B and Al fit into the same group with Ga, In and Tl. C and Si should be put with Ge, Sn and Pb; N and P certainly belong with As, Sb and Bi, and O with S, Se and Te; and, finally, the halogens F and Cl should not be separated from the other halogens, Br and I.

The elements are placed in such order that the atomic volumes are largest at the beginning and end of each series (or horizontal row) and smallest in the center. All the non-metallic elements (except hydrogen which is chemically more like the metals) are in the upper right hand corner of this table, while their chemical antipodes (the alkali metals) are diagonally across the table in the lower left hand corner. In the last four groups the numbers expressing the hydrogen valences of the members when added to the numbers expressing the maximum oxygen valences occurring in the same respective groups make the sum of 8.

45. The discovery of the elements He, Ne, A, Kr and X, which have so far resisted all efforts to cause them to enter into chemical combination with each other or with any other elements, and whose atomic weights place them together in one group between the halogens and the alkali metals, has led me to construct another table, given on p. 191, which perfectly preserves the natural classification of the elements, separates the decidedly negative from the decidedly positive, and places all the non-metallic elements together.

In this table the atomic volumes are greatest in the center and least at both ends of the horizontal rows. While the "short periods" are divided, this division is a natural one. It is a recognized feature of the periodic system that the properties of any element in the arrangement are intermediate between those of its neighbors on either side (in the same series) as well as between those of the elements above and below (in the same group). It is, therefore, natural that the indifferent elements He, Ne, A, Kr and X should be found between the intensely energetic halogens and alkali metals which are of opposite qualities.

46. Among the striking facts discovered by the Periodic System are the following:

a. The maximum valences occurring in each of the successive groups increase regularly from 1 to 7, corresponding with the numbers of the groups, with a maximum valence of 8 in the group headed by Fe. These valences are oxygen valences.

b. In the four groups headed by C, N, O and F, respectively, the hydrogen valences shown are -4 , -3 , -2 , and -1 , while the highest oxygen valences are $+4$, $+5$, $+6$, and $+7$.

c. When any two of the non-metallic elements enter into combination with each other in such a way that each atom of one is directly combined with each atom of the other, then, of the two elements so combined, that which stands to the right in any period has an invariable valence whenever it is combined with any element to its left, and that element which stands above in any group has an invariable valence whenever it is combined with any element below it.

d. All the elements in the second half of the table on p. 191 are positive elements.

e. In a group of negative elements the intensity of their chemical energy decreases as the atomic mass increases, as may be seen in the halogen group; but in a group of positive elements the intensity of chemical energy increases with the increasing atomic mass, as may be seen in the group of alkali metals and that of the alkaline-earth metals.

f. The elements having a greater atomic volume are relatively chemically energetic; inclination to enter into chemical combination decreases as density rises. Thus the elements near the eighth group exhibit greater chemical energy than those farther away from it.

g. Elements to the right of the eighth group in the table on p. 191 do not seem to form any true chemical compounds with each other except that a few of the metals form unstable compounds with hydrogen.

h. The gradual changes of properties in elements of any one family are marked in several groups, but most decidedly in the members of the carbon and nitrogen groups.

i. Strongly basic functions appear to be associated with low specific density and a low valence, the metals having a greater density and higher valence being feebler basic elements. Metals whose valences exceed 4 are never basic.

j. Strongly acidic functions are associated with high valences. While all the hydroxides of all the non-metallic elements are acidic (except that of hydrogen, water), the metallic hydroxides are usually acidic only when the valences of the metals exceed 4.

Of the several hydroxyl acids formed by any one element that acid is stronger in which that element exercises a higher valence (nitric acid is a very powerful acid; nitrous acid is a feeble acid, and hyponitrous acid still more feeble).

k. Elements to the left in the first seven columns of the table on p. 191 are positive elements in relation to elements to their right in the same columns, and elements whose position is lower are positive in their relation to elements above them. (See c.)

l. "Triads" of closely related elements frequently occur of which one has an atomic weight which is nearly one-half of the sum of the atomic weights of the other two. Such triads are formed by Al, Ga and In; Si, Ge and Sn; P, As and Sb; S, Se and Te; Cl, Br and I; Li, Na and K; K, Rb and Cs; Be, Mg and Ca; Ca, Sr and Ba; A, Kr and X.

m. The differences between the atomic weights of neighboring elements of the same group are often nearly multiples of 8 or of 16. Differences of 16 are shown between B and Al, C and Si, N and P, O and S, F and Cl, He and Ne, Li and Na, Na and K, Be and Mg, Mg and Ca.

n. It is evident from the Periodic System that no element can have a higher valence than 8.

o. The compounds formed by the elements of the halogen family with elements of the alkali family are all water-soluble; but the compounds formed by elements far from the center of the table and the elements with atomic weights exceeding 150 (in the lower part of that table) are generally insoluble.

p. The two elements which are recognized as invariably negative in all their compounds with other elements, and which do not seem to combine with each other, namely O and F, fall in positions beside each other in adjoining groups.

q. The two elements O and S, which perform the linking function in the formation of basic and acidic hydroxides and in the formation of oxygen salts and thio-salts, fall into positions next to each other in the same group.

r. The valence shown by any relatively negative element (when in combination with any relatively positive element in such a way that every atom of each element is linked directly to every atom of the other), deducted from 8, leaves a remainder expressing the highest valence possible to that element when positive. Thus as the valence of negative carbon (as in H_4C) is 4, the highest valence possible to positive carbon is 4 (as in CO_2); as the valence of negative nitrogen (as in H_3N) is 3, the highest valence possible to positive N can not exceed 5 (it is 5 in N_2O_5 and in the nitrates); as the valence of negative sulphur is 2 as in H_2S , its highest possible

valence is 6 (as in SO_3 and the sulphates); and as the valence of Cl in all chlorides is 1, its highest possible valence when relatively positive (in the oxygen salts containing Cl as the acidic element) must be 7 (as it is in the perchlorates).

s. The four principal elements contained in organic substances are H, C, N and O. Of these H is invariably a positive monad in all organic compounds, and O invariably a negative dyad element, while C and N are both negative in relation to H but positive in relation to O, and both C and N possess striking powers as linking elements which may be either exclusively positive, exclusively negative, or partly positive and partly negative. Carbon is positive toward N. It exhibits a wonderful power to form chains.

The ruling valences of these four elements in organic compounds are 4 (C), 3 (N), 2 (O), and 1 (H). These elements occupy suggestive positions in the periodic system, and have low specific weights and low atomic weights.

Carbon has a great variety of algebraic combining numbers; thus it has a combining value of -4 in H_4C and all other compounds in which all the carbon bonds are united to hydrogen or other positive elements; -2 in all compounds in which three of the carbon bonds are united to positive atoms and the fourth to some negative element; 0 in all compounds in which one-half of the carbon bonds are positive and the other half negative; $+2$ in all compounds in which three of the carbon bonds are united to negative atoms and the fourth to a positive atom (and in isocyanides in which the carbon atom has only two bonds, both of which are united to nitrogen); and $+4$ in all compounds in which all the carbon bonds are united to negative atoms or elements.

CHAPTER III.

CLASSIFICATION OF INORGANIC CHEMICAL COMPOUNDS.

47. Chemical notation, polarity, valence, and the structure, classification and nomenclature of chemical compounds are, of course, intimately related to each other. In the two preceding chapters we have treated of the elements, chemical combining power, polarity and valence, and it was necessary to employ the symbolic formulas and the technical names of many compounds to make the subjects treated of clear to the student. The formulas introduced and the technical nomenclature used were to a great extent self-explanatory, or were defined or explained sufficiently to serve the purpose of their employment.

We shall now more fully treat of the most important classes of inorganic chemical compounds and their structure. The student is strongly advised, after studying each of these subjects in the order in which they are presented, to read all a second time, or even a third and fourth time.

48. A scientific classification of chemical compounds must be based first upon structure and next upon properties. It should take into account the number of component elements and their respective properties and combining values, and the inter-atomic linking and general chemical behavior of the compounds.

Our universally employed nomenclature for inorganic compounds is old and although it has undergone many changes from time to time it is not perfect. It was devised at a time when the electro-chemical theories of the great Berzelius ruled. But as modern chemical theories still recognize chemical polarity, positive and negative elements and positive and negative ions and radicals, although in a modified way, we find that the old nomenclature is still substantially the same and serviceable.

Some of the popular designations of chemical compounds, however, do not agree with scientific classification. Common names, even when unsystematic and inconsistent, may not cause serious confusion, but when they are used their unscientific character should be understood. The common expressions "sunrise" and "sunset" do no harm so long as we know that the rising and setting of the sun are only appearances. Students of chemistry must not permit careless nomenclature to obscure radical differences in the structure of the substances named.

Until comparatively recently the acidic chromic oxide or "chromic anhydride" was misnamed chromic acid; arsenous oxide was misnamed arsenous acid; potassium dichromate was misnamed bichromate; sodium monothiosulphate was misnamed hyposulphite; sodium tetraborate was misnamed baborate, etc. We still give the name "nitric oxide" to the compound NO , although the only compound which can, consistently with our system of nomenclature, be called nitric oxide must be N_2O_5 .

We place strictly binary compounds in the same class with compounds containing three or more elements; thus sulphides are called salts, although they are perfectly analogous to the oxides; we call the fluoride, chloride, bromide, iodide and sulphide of hydrogen acids and thus class them with the acidic hydroxides; we call the fluorides, chlorides, bromides and iodides of the metals salts and thus class them with the hypochlorites, bromates, periodates, sulphates and other compounds containing linking oxygen or linking sulphur and, therefore, of radically different structure. The student will see at a glance that HCl and H_2S do not resemble $(\text{HIO})_2\text{SO}_2$ or HIONO_2 in structure, and that NaCl and K_2S do not resemble KOCLO_2 . But the fluorides, chlorides, bromides, iodides and sulphides of hydrogen and of the metals are of precisely the same structure as those of other elements. They are binary compounds.

If these facts are clearly understood and kept in mind the student will not be misled.

Many chemical compounds of exceptional structure exist in the mineral kingdom which can not be made in the laboratory

because the conditions under which they were formed and which were necessary to their formation can not be reproduced. Many other compounds have been made in the laboratory which are also of exceptional structure, unstable and of no importance. But in this chapter we shall discuss chiefly common compounds of typical structure.

49. The great typical classes of common inorganic chemical compounds are as follows:

A. Binary Compounds:

- | | | |
|---------------|----------------|------------------|
| 1. Fluorides. | 5. Oxides. | 9. Nitrides. |
| 2. Chlorides. | 6. Sulphides. | 10. Phosphides. |
| 3. Bromides. | 7. Selenides. | 11. Arsenides. |
| 4. Iodides. | 8. Tellurides. | 12. Antimonides. |
-
13. Carbides.
14. Silicides.
-

The binary compounds of hydrogen with the halogens and with sulphur, selenium and tellurium are generally classed among the acids. They are called "hydrogen acids" or "hydroacids," to distinguish them from the hydroxyl acids and the thio-acids.

The binary compounds of the metals with the halogens and with sulphur are generally classed among the salts.

B. Hydroxides.

1. Basic hydroxides, or bases.
2. Acidic hydroxides, or hydroxyl acids.

C. Hydrosulphides.

1. Basic hydrosulphides or thio-bases.
2. Acidic hydrosulphides or thio-acids.

D. Oxygen Salts.

E. Thio-Salts.

F. Other Compounds—those not belonging to either of classes A, B, C, D, or E.

It will be seen that in accordance with this classification the acids, bases and salts belong to several classes according to their structure.

The **acids** are of three classes, as follows:

1. **Binary acids or hydrogen acids**, of which there are seven, namely HIF , HCl , HBr , HI , H_2S , H_2Se and H_2Te .
2. **Hydroxyl acids**, which contain hydrogen and oxygen together with the acidic element.
3. **Thio-acids**, which contain hydrogen and sulphur, together with the acidic element and which may contain oxygen in addition.

The **Bases** are of two classes, namely:

1. **Basic hydroxides**, such as KOH , $\text{Ca}(\text{OH})_2$, etc.
2. **Basic hydrosulphides**, such as KSH , H_4NSH , etc.

The common **Salts** are of three classes, as follows:

1. **Binary salts**, including the fluorides, chlorides, bromides, iodides and sulphides of metals.
2. **Oxygen salts.**
3. **Thio-salts.**

50. When structure is made the chief basis of classification no difficulty is experienced except in making distinction between basic and acidic hydroxides, and the difficulty in that particular is due to the fact that some elements perform both basic and acidic functions. Thus the hydroxides of aluminum, zinc, iron, antimony and boron form salts with both acids and bases. But this difficulty is not removed by any method of classification.

The ionic theory has furnished us with a new basis of classification of acids, bases and salts. As all known acids which have been ionized yield hydrogen ions, and as hydrogen ions have not been obtained from any other compounds, the modern definition of acids makes that property of the acids their chief characteristic. The chief characteristic of bases is held to be the fact that they yield hydroxyl ions, and the salts, according to this system of classification, are the products formed by replacing the cation (hydrogen) of an acid with a metal, or by replacing the anion (hydroxyl) of a base with the

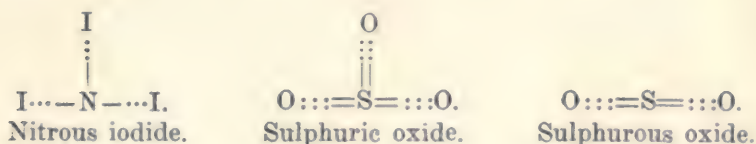
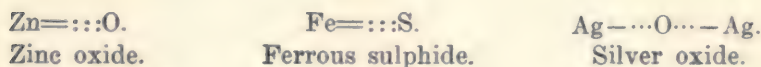
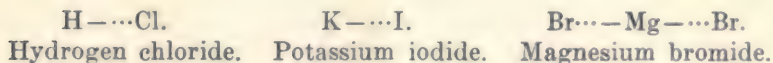
anion of an acid. The acids, bases and salts which are insoluble or have not been ionized are identified by their structural analogies, so that by this system, too, structure is of great importance. But as binary compounds are included among the acids and salts according to the definitions based on the ionic theory, the difficulties attending the classification of compounds is greater when those definitions are used than when structure is made the chief basis of differentiation.

These facts will presently become apparent.

51. Binary compounds are compounds containing but two elements united in such a way that each atom of one element is in immediate combination with each atom of the other and in which each atom of either of the component elements exhibits the same valence as that of any other atom of the same element.

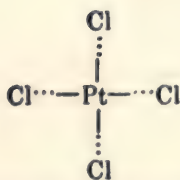
Any compound of two elements containing in its molecule two or more atoms of any given element in immediate combination with each other (as the compound HOOH), or containing two or more atoms of the same element, but with different valences (as the compound CaSS_4), is not a true binary compound in the strict sense of that term. A true binary compound is composed of one relatively positive element and one relatively negative element.

Examples of binary compounds are represented by the following formulas in which the solid lines stand for positive bonds (or charges of positive electricity) and the dotted lines for negative bonds (or charges of negative electricity):

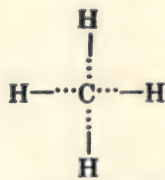
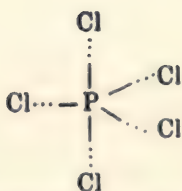




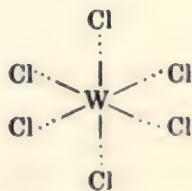
Ferric oxide.



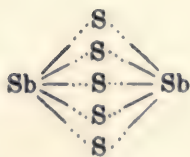
Platinic chloride.

Methane or
hydrogen carbide.

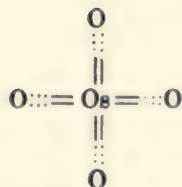
Phosphoric chloride.



Tungstic chloride.



Antimonic sulphide.



Osmic oxide.

52. A further analysis of the structure and properties of binary compounds may be profitably presented as follows:

1. **Examples of binary hydrogen compounds.**

HF	}	These are all called "acids."
HCl		
HBr		
HI		
H ₂ S		
H ₂ Se		
H ₂ Te		

H₂O, water, is neither an acid nor a base.

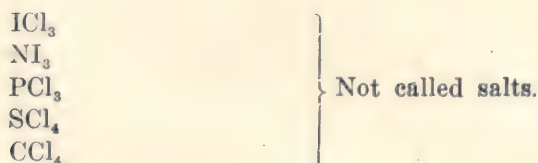
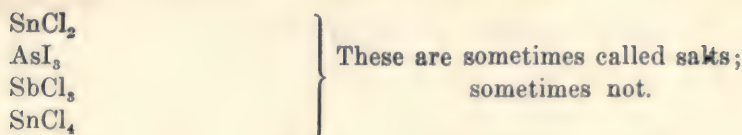
H₃N is ammonia, which forms the strongly basic ammonium hydroxide.

H ₃ P	}	These are neither acids nor bases.
H ₃ As		
H ₃ Sb		
H ₄ C		
H ₄ Si		

2. **Examples of binary compounds of the halogens.**

All the hydrogen compounds of the halogens are called acids; the halogen compounds of the metals are called salts; the halogen compounds of the non-metallic elements are neither acids nor salts:

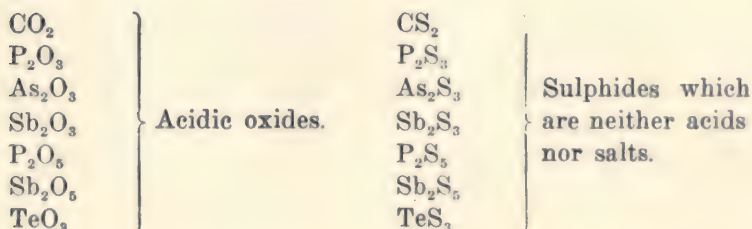
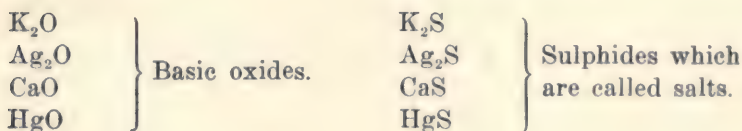
LiCl	}	These are called salts.
NaCl		
KCl		
AgI		
HgCl		
MgCl ₂		
CaCl ₂		
BaCl ₂		
AlCl ₃		
FeCl ₂		
FeCl ₃		
ZnCl ₂		
PtCl ₄		



3. Examples of oxides and sulphides.

H_2O ; water.

H_2S ; called an acid.



Basic oxides are the oxides of metals capable of performing basic functions in the formation of salts, or forming basic hydroxides with water. **Acidic oxides** are the oxides of elements capable of performing the acidic function in the formation of salts, or forming acids with water. Basic oxides and acidic oxides form salts with each other.

Basic sulphides correspond to the basic oxides. They are the sulphides of metals capable of performing the basic function in the formation of thio-salts. **Acidic sulphides** correspond to the acidic oxides and are the sulphides of elements capable of performing the acidic function in the formation of

thio-salts. Na_2S is a basic sulphide, but is now called a "salt"; Sb_2S_3 is an acidie sulphide, but is sometimes called a salt; and Na_3SbS_3 is a thio-salt. It is customary and correct to say that bases and acids form salts with each other; but it may puzzle the student to grasp the proposition that one salt combines with another salt to form a third salt, as illustrated by the following reaction: $3\text{Na}_2\text{S} + \text{Sb}_2\text{S}_3 = 2\text{Na}_3\text{SbS}_3$.

Fe_2S_3 is called a salt and Sb_2S_3 is not less entitled to the same designation.

The difficulties rendered apparent in this paragraph are avoided by giving to all fluorides, chlorides, bromides, iodides, sulphides, selenides and tellurides those already established specific names instead of separating each of these classes of binary compounds into three groups—those that have acid properties, those that are called salts, and those that are neither acids nor salts.

The student must learn that hydrogen fluoride, hydrogen chloride, hydrogen bromide and hydrogen iodide have strongly marked acid properties and yield hydrogen ions; he must know what hydrochloric acid is; he must know that the halides of the metals are generally called salts, and that even the sulphides of the metals are called by that name; but he must at the same time remember always that other binary compounds have the same structure as that possessed by the binary acids and salts and that this structure is radically different from that of other acids and salts.

53. Hydroxides are the compounds formed by the chemical elements with the compound radical **hydroxyl** (OH or HO).

They are often produced by reaction of the oxides with water.

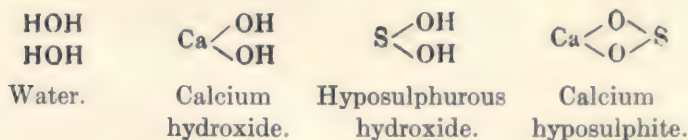
The most common hydroxide is water, HOH , or hydrogen hydroxide. It may be called both an oxide and a hydroxide. It is neither an acid nor a base, but intermediate between the acids and bases, and the structural type of the most numerous classes of acids, bases and salts.

When a part of the hydrogen of water is replaced by a basic element a base is formed; when a part of the hydrogen is replaced by an acidie element an acid results, and when a part

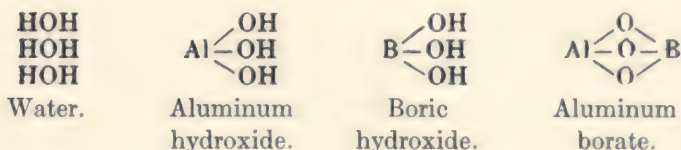
of the hydrogen is replaced by a basic element and another part by an acidic element a salt is formed.

Thus HOH is water; KOH is a base; ClOH is an acid; KOCl is a salt.

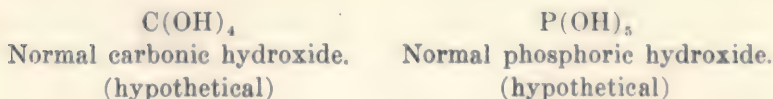
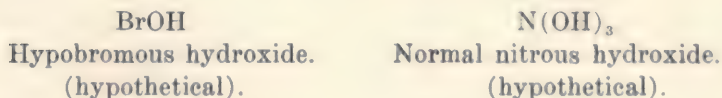
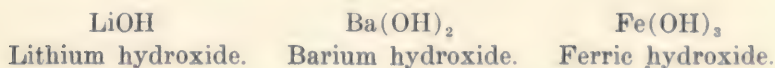
Taking two molecules of water as our starting point, we can have—



Starting with three molecules of water we may have—



The hydroxides represented in the preceding comparisons are of **normal structure**. A hydroxide of normal structure is one containing no oxygen or hydrogen except that of the hydroxyl, or containing in each molecule as many hydroxyl groups as the third element can hold in combination according to its valence. The following are hydroxides of normal structure or normal hydroxides:



$S(OH)_6$
Sulphuric hydroxide
of normal structure.

$Cl(OH)_7$
Normal perchloric hydroxide.
(hypothetical).

But the inorganic hydroxides are usually not of normal structure. Normal acidic hydroxides are rare. The acids are, instead, usually meta-hydroxides.

54. Meta-hydroxides differ from the normal hydroxides by OnH_{2n} , that is, by one or more oxygen atoms together with twice as many hydrogen atoms.

It will be seen that OnH_{2n} is equivalent to any multiple of H_2O , and in fact when a normal hydroxide is changed to a meta-hydroxide it splits up into meta-hydroxide and water. It would be incorrect, however, to say that "water is split off," for hydroxides do not contain the group H_2O . A correct statement is that **hydrogen and oxygen are split off and combine with each other to form water.***

55. When two hydrogen atoms and one oxygen atom are together split off from a hydroxide of normal composition and form **one molecule of water**, the resulting meta-hydroxide is called a **mono-meta-hydroxide**; when twice as many atoms of hydrogen and oxygen are separated and two molecules of water are formed a **di-meta-hydroxide** results; a **tri-meta-hydroxide** remains if three molecules of water are formed; a **tetra-meta-hydroxide** when four molecules are formed; a **penta-meta-hydroxide** when five molecules of water are formed, etc.

56. It is evident that no meta-hydroxide can be formed out of one molecule of any hydroxide of normal structure containing less than three hydroxyl groups.

*Hydroxides were formerly called "hydrates." That style of nomenclature arose from the old dualistic theory of the formation of chemical compounds, which assumed that the hydroxides were compounds of the oxides and water. Thus $(HO)_2SO_2$ was supposed to be $SO_3 + H_2O$; $(HO)_4SO$ was supposed to be $SO_3 + 2H_2O$; and $(HO)_6S$ was $SO_3 + 3H_2O$. Sulphuric oxide, SO_3 , was at that time called sulphuric acid and H_2SO_4 , H_4SO_5 and H_6SO_6 were regarded as the three "hydrates" of SO_3 .

Calcium hydroxide $Ca(OH)_2$ was then called calcium hydrate because it was held to be $CaO + H_2O$.

Hydrates are molecular combinations containing water.

Monovalent chlorine forms the normal hydroxide HOCl called hypochlorous acid, but there can be no hypochlorous meta-hydroxide. Hyposulphurous hydroxide of normal structure is $(\text{HO})_2\text{S}$ and no meta-hydroxide can be formed out of it. Meta-hydroxides can not be formed by any monads or dyads.

But $(\text{HO})_3\text{N}$, which is normal nitrous hydroxide, forms HONO or HNO_2 , which is nitrous mono-meta-hydroxide, the common nitrous acid.

The normal hydroxide of tetravalent sulphur is $(\text{HO})_4\text{S}$, and its mono-meta-hydroxide is $(\text{HO})_2\text{SO}$ or H_2SO_3 , called sulphurous acid.

The normal hydroxide of trivalent iron is $\text{Fe}(\text{OH})_3$ and its mono-meta-hydroxide is OFeOH .

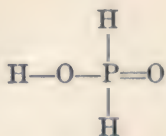
The normal hydroxide of hexavalent sulphur is $(\text{HO})_6\text{S}$, known in crystalline form; its mono-meta-hydroxide is $(\text{HO})_4\text{SO}$, or H_4SO_5 , known by several of its salts, and its di-meta-hydroxide is $(\text{HO})_2\text{SO}_2$ or H_2SO_4 , which is the common sulphuric acid.

The normal hydroxide of heptavalent chlorine is $(\text{HO})_7\text{Cl}$; its mono-meta-hydroxide is $(\text{HO})_5\text{ClO}$; its di-meta-hydroxide is $(\text{HO})_3\text{ClO}_2$; its tri-meta-hydroxide HOClO_3 , or HClO_4 .

The normal hydroxide of pentavalent nitrogen is $(\text{HO})_5\text{N}$; its mono-meta-hydroxide is $(\text{HO})_3\text{NO}$; and its di-meta-hydroxide HONO_2 or HNO_3 , the common nitric acid.

But meta-hydroxides are also formed out of more than one molecule of the normal hydroxide. Thus $\text{H}_4\text{Fe}_2\text{O}_7$ is mono-meta-di-ferrie hydroxide formed from two molecules of $\text{Fe}(\text{OH})_3$; $\text{H}_4\text{P}_2\text{O}_7$ is tri-meta-di-phosphoric hydroxide; and $\text{H}_2\text{B}_4\text{O}_7$ is penta-meta-tetra-boric hydroxide.

57. Other hydroxides exist which differ from those of normal structure by containing **more** hydrogen and oxygen instead of less, as for instance the well known hypophosphorous acid, HOPH_2O , having the structure



It will be seen that in this acid the acidic element (the P) holds hydrogen in immediate combination. This condition also exists in several other compounds.

Phosphorous acid, $(\text{HO})_2\text{PHO}$, contains only two hydroxyl groups and hence only two atoms of replaceable hydrogen for only the hydrogen of the hydroxyl is the replaceable hydrogen of acids; arsenous acid is of the same structure.

58. The oxygen of the hydroxyl of any acid or base is called **linking oxygen** because it links the replaceable hydrogen to the third element—the basic element of a base, the acidic element of an acid.

This linking oxygen remains in any salt derived from any hydroxide. In salts the linking oxygen links the basic element to the acidic element.

Any additional oxygen contained in the inorganic acids, bases and salts, is “non-linking oxygen.”

59. Examples of hydroxides and metahydroxides:

Bases.	Acids.
$\text{K}(\text{OH})$	$\text{H}(\text{OCl})$
$\text{Li}(\text{OH})$	$\text{H}(\text{OClO}_2)$
$\text{Na}(\text{OH})$	$\text{H}(\text{OClO}_3)$
$\text{Rb}(\text{OH})$	$\text{H}_2(\text{O}_2\text{SO})$
$\text{Cs}(\text{OH})$	$\text{H}_2(\text{O}_2\text{SO}_2)$
$\text{Ca}(\text{OH})_2$	$\text{H}(\text{ONO})$
$\text{Sr}(\text{OH})_2$	$\text{H}(\text{ONO}_2)$
$\text{Ba}(\text{OH})_2$	$\text{H}(\text{OPH}_2\text{O})$
$\text{Mg}(\text{OH})_2$	$\text{H}_2(\text{O}_2\text{PHO})$
$\text{Zn}(\text{OH})_2$	$\text{H}_3(\text{O}_2\text{PO})$
$\text{Cd}(\text{OH})_2$	$\text{H}(\text{OPO}_2)$
$\text{Fe}(\text{OH})_2$	$\text{H}(\text{OAsO})$
$\text{Mn}(\text{OH})_2$	$\text{H}_2(\text{O}_2\text{AsHO})$
$\text{Pb}(\text{OH})_2$	$\text{H}_3(\text{O}_3\text{AsO})$
$\text{Cu}(\text{OH})_2$	$\text{H}_4(\text{O}_4\text{C})$
$\text{Al}(\text{OH})_3$	$\text{H}_2(\text{O}_2\text{CO})$
$\text{Fe}(\text{OH})_3$	$\text{H}_3(\text{O}_3\text{B})$
$\text{Bi}(\text{OH})_3$	$\text{H}(\text{OBO})$

60. Acids. The term "acid" was originally applied to liquids possessing the following general properties:

They have a strongly acid or sour taste, are destructive in their effects upon most organic compounds, turn blue litmus red, and neutralize the properties of the bases with which they react to form salts and water.

The most characteristic acids are the so-called "strong acids," which are water-soluble, dissolve certain metals and metallic oxides with which they form water-soluble salts, and also dissolve certain other substances insoluble in water and other common solvents. This solution effected by acids is "chemical solution," the acid itself is decomposed as well as the substance dissolved, and new substances are formed. We say that acids attack many substances and that they must, therefore, be kept in containers made of acid-proof materials like glass. But it would be more correct to say that the acids are so unstable that other substances attack and decompose them.

Insoluble acids are tasteless, non-destructive, and do not affect the color of litmus.

All acids contain hydrogen which can be exchanged for a metal, with the result that a salt is formed, and all acids when ionized yield cations of hydrogen. But the insoluble acids can not be ionized, and many soluble substances which are not acids and which contain no hydrogen turn blue litmus red.

From these facts it is evident that the acids must be identified not by their taste, nor by their action on litmus, nor by their cations, but by their composition and structure and by the salts derived from them.

Acids have been described as compounds from which hydrogen can be liberated by some metal like Zn or Mg with the result that a salt is formed. But if potassium zincate is a salt, as it is commonly held to be, because it has the typical structure of a salt, the KOH would under that definition be an acid, for zinc liberates hydrogen from KOH and forms K_2ZnO_2 . But KOH is a strong base, the very opposite of an acid.

61. All acids have the following properties in common: They contain hydrogen which can be replaced by a metal with the result that a salt is formed the structure of which is perfectly analogous to that of the acid from which the salt is de-

rived. If water-soluble they yield hydrogen ions and turn blue litmus red.

There are three classes of acids according to present definitions, namely:

1. **Hydrogen acids**, or hydracids, which consist of all the binary hydrogen compounds containing not more than two hydrogen atoms, except water.

2. **Hydroxyl acids** are the acidic hydroxides and meta-hydroxides.

All elements forming binary compounds which at ordinary temperatures are gases form acidic hydroxides and meta-hydroxides. In other words, all the hydroxides and meta-hydroxides of non-metallic elements are acids.

All hydroxides and meta-hydroxides of elements exercising a valence exceeding 4 are acids. [Metals rarely perform the acidic function when their valence is below 4; but a few exceptions may be noted in which such metals form salts with powerful bases, as shown by the zincates and aluminates of the alkali metals. Other compounds containing atoms of metals linked together by oxygen or sulphur are assumed to be salts when their structure is incompatible with any other assumption but quite analogous to that of common oxygen salts or thio-salts.]

All organic acids contain the characteristic group called carboxyl, COOH , which consists of carbonyl, CO , and hydroxyl, OH . Hence all organic acids as well as all inorganic oxygen acids contain hydroxyl and their replaceable hydrogen is the hydrogen of that hydroxyl.

All known hydroxides of elements capable of performing the acidic function are called acids even when salts derived from them are unknown. Purely hypothetical acidic hydroxides without any known salts may be theoretically considered.

3. **Thio-acids** are acids whose structure is perfectly analogous to that of the hydroxyl acids, but in which a part or all of the oxygen is replaced by sulphur performing the same functions that are performed by oxygen in the hydroxyl acids.

Carbonic acid is $(\text{HO})_2\text{CO}$ or H_2CO_3 . Thiocarbonic acid is $(\text{HS})_2\text{CS}$ or H_2CS_3 .

Sulphuric acid (that is, the common or di-meta-sulphuric

acid) is $(\text{HO})_2\text{SO}_2$ or H_2SO_4 . Mono-thio-sulphuric acid is $\text{H}_2\text{SO}_3\text{S}$, the sodium salt of which is the important "sodium thiosulphate." Di-thio-sulphuric acid is $\text{H}_2\text{SO}_2\text{S}_2$. Tri-thio-sulphuric acid is H_2SOS_3 . Tetra-thio-sulphuric acid is H_2SS_4 .

62. All of the hydrogen of a hydrogen acid is "replaceable hydrogen." The replaceable hydrogen of any hydroxyl acid is the hydrogen of its hydroxyl and no other hydrogen, and in a few instances not even all the hydrogen of the hydroxyl is replaceable.

The "replaceable hydrogen" of any acid may be replaced by either a metal or by a compound radical capable of performing the basic function, and a salt thus formed. Among the common basic compound radicals forming salts with the acids are ammonium, H_4N , and the hydrocarbon radicals CH_3 , C_2H_5 , C_6H_5 , etc. The alkaloids form salts with the acids in the same manner as H_3N —that is, without the formation of water as explained elsewhere (par. 41).

63. The **acidic element** of an inorganic hydroxyl acid is that element which in combination with the hydroxyl, with or without additional oxygen or hydrogen, constitutes that acid.

The inorganic acids are named after their acidic elements. Thus the acidic element of nitric acid, nitrous acid and hypobitrous acid is nitrogen; the acidic element of sulphuric, sulphurous and hyposulphurous acids is sulphur; that of perchloric, chloric, chlorous and hypochlorous acids is chlorine.

Acidic elements are generally more decidedly acidic the greater their algebraic combining value is. Of any two acids formed by the same acidic element and containing the same number of hydrogen atoms the stronger acid is the one in which that element has the higher true combining value, and which usually contains the greater proportion of oxygen, as may be seen by comparing $(\text{HO})_2\text{SO}_2$ with $(\text{HO})_2\text{SO}$, HONO_2 with HONO , HOPO_2 with HOPH_2O , and HOCLO_2 with HOCl . Thus sulphur with a combining value of $+6$ is more decidedly acidic than sulphur with a combining value of $+4$, etc.

The acidic elements of the acids are positive elements because they are in immediate combination with oxygen.

When a salt is formed by the acid the structure of the salt is the same as that of the acid by which it was formed (except

when H and O are split off to form water) as illustrated by the following reaction: $(\text{HO})_6\text{S} + 2\text{KOH} = \text{K}_2\text{SO}_4 + 4\text{H}_2\text{O}$. The acidic element of the acid, therefore, retains that designation in the salt. (See also par. 53.)

Whenever the valence of the acidic element is an odd number the molecule of the acid must contain an odd number of hydrogen atoms (except when an even number of atoms of the acidic element is contained in it).

When the valence of the acidic element is an even number the molecule of the acid contains an even number of hydrogen atoms.

64. Hydroxyl acids of normal structure. These are the normal hydroxides of acidic elements. [They are sometimes called "normal acids," but students are advised not to give them such designations because misunderstanding may result on account of the universal use of the term "normal" in connection with volumetric test-solutions. Thus sulphuric hydroxide of normal structure or "normal sulphuric acid" is $(\text{HO})_6\text{S}$, but "normal sulphuric acid volumetric solution" is a solution containing 48.68 Gm of di-meta-sulphuric acid in each liter.]

Boric acid, H_3BO_3 , is of normal structure. Sulphuric hydroxide of normal structure, $(\text{HO})_6\text{S}$, can be obtained in crystals. Several of the normal acidic hydroxides probably exist in the "dilute acids," but when salts are produced from the solutions of those acids it usually happens that only a part of their hydrogen is replaced and meta-salts are formed.

[Acidic hydroxides of normal structure are frequently called "ortho-acids." We thus read of ortho-carbonic acid, $(\text{HO})_4\text{C}$, and ortho-silicic acid, $(\text{HO})_4\text{Si}$; but the prefix "ortho-" is misleading. The so-called ortho-phosphoric acid instead of being $(\text{HO})_5\text{P}$, or normal phosphoric hydroxide, is mono-meta-phosphoric acid, $(\text{HO})_3\text{PO}$. The prefix "ortho-" does not mean **normal** in the sense in which that word is used in connection with the structure of acids, bases and salts; it means ordinary or common or regular.]

65. Meta-acids are the acidic meta-hydroxides (par. 52 and 53).

Normal sulphuric hydroxide, or sulphuric acid of normal

structure, is $(\text{HO})_6\text{S}$. Mono-meta-sulphuric acid is $(\text{HO})_4\text{SO}$. Ferrous sulphate, zinc sulphate and some other sulphates are not di-meta-sulphates (the salts of H_2SO_4) but mono-meta-sulphates. Di-meta-sulphuric acid is $(\text{HO})_2\text{SO}_2$, which is the common sulphuric acid.*

Common perchlorates are the salts of tri-meta-perchloric acid.

Common chlorates are di-meta-chlorates.

Hypochlorites are of normal composition.

Common sulphates are di-meta-sulphates.

Ferrous sulphate is FeH_2SO_5 ; zinc sulphate is ZnH_2SO_5 and magnesium sulphate MgH_2SO_5 .

Common nitrates are the salts of di-meta-nitric acid, or di-meta-nitrates.

Common phosphates are mono-meta-phosphates, the salts of mono-meta-phosphoric acid, H_3PO_4 , commonly called ortho-phosphoric acid.

HPO_3 is di-meta-phosphoric acid.

The "pyrophosphates" are the salts of tri-meta-diphosphoric acid, $\text{H}_4\text{P}_2\text{O}_7$.

The common carbonates are meta-carbonates, derived from mono-meta-carbonic hydroxide.

Borax is a penta-meta-tetra-borate, derived from $\text{H}_2\text{B}_4\text{O}_7$.

$\text{H}_2\text{S}_2\text{O}_7$ is penta-meta-disulphuric acid commonly called per-sulphuric or pyrosulphuric acid.

66. The stronger acids may be expected to decompose the

*Chemical combination is attended by the generation of heat. The rise of temperature is often marked. The molecular weight of SO_3 is 80; that of water is 18. When 80 parts of SO_3 and 18 parts of H_2O are mixed, a violent reaction takes place with great evolution of heat as H_2SO_4 is formed. The molecular weight of H_2SO_4 is 98. When 98 parts of H_2SO_4 and 18 parts of H_2O are mixed a violent reaction and great rise of temperature again take place and H_4SO_5 is formed, the molecular weight of which is $98+18$ or 116. When 116 parts of H_4SO_5 and 18 parts of H_2O are mixed a reaction occurs again but much less violent and with less evolution of heat, and H_2SO_5 or $(\text{HO})_4\text{S}$ is formed. The addition of water to $(\text{HO})_4\text{S}$ causes no elevation of temperature because no further chemical reaction is possible. The reactions referred to are:

1. $\text{SO}_3 + \text{H}_2\text{O} = \text{H}_2\text{SO}_4$ or $(\text{HO})_2\text{SO}_2$.
2. $\text{H}_2\text{SO}_4 + \text{H}_2\text{O} = \text{H}_4\text{SO}_5$.
3. $\text{H}_4\text{SO}_5 + \text{H}_2\text{O} = (\text{HO})_4\text{S}$.

salts of feeble acids, but feeble acids do not decompose the salts of stronger acids under ordinary conditions, except that the salts of more volatile acids are decomposed by less volatile acids, and that insoluble salts resist decomposition by acids forming soluble salts of the same basic elements while the soluble salts are generally decomposed by acids forming insoluble salts with the same bases.

67. The inorganic Bases are the hydroxides of metals having a valence of 1, 2 or 3.*

The anion of a base is its hydroxyl.

Bases react with acids to form salts and water.

Water-soluble bases turn red litmus blue.

The **basic element** of an inorganic base or of a metallic salt is its cation (the metal performing the basic function).

68. Alkalies. The most strongly characteristic basic hydroxides are the so-called **alkalies**. These are the water-soluble hydroxides of the monovalent metals Cs, Rb, K, Na and Li.

The hydroxides of the divalent alkaline-earth metals, Ba, Sr and Ca, are sometimes also called alkalies; they are comparatively sparingly water-soluble. Even the hydroxide of Mg has an alkaline reaction on litmus.

The metals named have a specific density below 5 and lower than that of their own oxides.

The common strong alkalies are KOH and NaOH. Ammonium hydroxide, H_4NOH , which is strongly alkaline, is generally classed with the alkalies.

Alkalies have a lye-like taste, are destructive in their action upon many organic substances, turn red litmus blue, and neutralize the properties of the acids. The salts of potassium, sodium and ammonium are generally quite readily water-soluble.

69. Insoluble bases and basic oxides exhibit but feebly, if at all, the taste and litmus reaction of the alkalies, and are not destructive.

Strong bases usually decompose the compounds of less strongly basic metals; but insoluble compounds often resist their action.

[*But tetravalent cerium is also basic, and metals with a valence below 4 sometimes perform acidic functions.

Metals of low valence are generally more strongly basic than those of higher valence; but heavy metals are not as strongly basic as the lighter metals, regardless of valence.

Meta-bases are basic meta-hydroxides. They are not as common as meta-acids. Meta-bases are formed by aluminum and iron: OAlOH and OFeOH .

70. The opposite qualities of acids and bases are striking.

The "strong acids" and the "alkalies" are all destructive; but while no two acids neutralize each other and no two alkalies neutralize each other, any acid may be neutralized by a sufficient quantity of any base, however feeble, and any alkali may be neutralized by a sufficient quantity of any acid, however feeble.

Water-soluble acids turn blue litmus red, and water-soluble bases turn red litmus blue. But water-soluble salts formed by strong acids with strong bases are neutral to litmus paper, while water-soluble salts formed by strong acids with feeble bases turn blue litmus red, and water-soluble salts formed by strong bases with feeble acids turn red litmus blue.

The addition of one acid to another does not remove the acid taste, and the addition of one alkali to another does not neutralize the lye-like taste. But acids and bases neutralize each other in this particular as well as in their destructiveness and action on litmus. Acids and bases are, therefore, opposites.

It was at one time taught that acids owed their characteristic sour taste and acid properties to the oxygen in them. But the bases also contain oxygen. When hydrogen chloride was found to resemble the strong acids in that it had a strongly acid taste, dissolved certain metals and other substances not soluble in water, turned blue litmus red, neutralized the bases, and formed with the bases compounds which in several respects resembled the salts formed by the strong acids, the chloride of hydrogen was called an acid.

As the hydroxyl acids contain hydrogen as well as oxygen, and hydrogen chloride contains no oxygen, it was then concluded that the acid properties of the acids must be attributed to the hydrogen instead of to the oxygen. But the basic hydroxides and their opposites, the acidic hydroxides, are all compounds containing both hydrogen and oxygen.

All acids, when ionized, yield hydrogen ions, and all bases yield hydroxyl ions. But the hydrogen ions of the hydroxyl acids are their **positive** ions, while the hydroxyl ions of the bases are **negative** ions (their free bonds being oxygen bonds).

The hydrogen and oxygen of both acids and bases are united into the group called hydroxyl (OH). Evidently, then, acid properties and basic properties are due not to the hydrogen nor to the oxygen, nor to the hydroxyl, but chiefly to the atom or group of atoms to which the hydroxyl is united.

Potassium hydroxide, KOH, is a base. Hypochlorous hydroxide, ClOH, is an acid. Both contain hydrogen and oxygen united to a third element. The third element of the KOH is the K, which is a **basic element**. The third element of the ClOH is the Cl, which is an **acidic element**. The basic character of KOH is due to the K and to the fact that the K is united to OH. The acid character of ClOH is due to the Cl and to the fact that the Cl is united to OH.

The statement that the acid character of nitric acid is due to the acidic element nitrogen simply means that nitrogen, like all other non-metallic elements forming hydroxides, is of such a nature that its hydroxides are acidic. The acid properties of HONO_2 are due not to the N alone but also to the fact that this N is in immediate combination with hydroxyl. The basic properties of H_4NOH are due not to the N alone but also to the H with which that N is in immediate combination. But the N of HONO_2 and that of the H_4NOH are quite different from each other, for N is positive toward oxygen but negative in relation to hydrogen.

The carbonyl, CO, is as necessary to an organic acid as is the acidic element to an inorganic acid. It should not be overlooked, however, that the double group carboxyl, OC.OH or CO.OH , is united to one of the atoms of the remainder of the molecule of the acid by a negative carbon bond. This carbon bond of the carboxyl is united to another carbon atom [KO.CO.OH is not an acid].

Carbon is necessary to the general properties of H_3COH as well as to $(\text{HO})_2\text{CO}$ and $\text{H}_3\text{C.CO.OH}$; but it is evident that radically different properties are possessed by atomic groups composed of C united to H and atomic groups of C united to

O. Carbon united to H is of negative polarity, while that united to O is positive carbon.

An acid reaction on litmus is produced by various compounds which are neither acids nor salts, and which contain no hydrogen. Among the common compounds which are not acids but which have an acid reaction are zinc chloride, aluminum chloride, gold chloride, ferric and ferrous chloride, mercuric chloride, zinc bromide and iodide, the alums, the sulphates of zinc, iron and aluminum, and lead nitrate.

Among the common compounds which turn red litmus blue but which are not bases and contain no hydroxyl are lithium bromide, sodium pyrophosphate, lithium benzoate, potassium acetate, potassium cyanide, and potassium dichromate.

71. Salts. The common name salt was originally applied to all solid water-soluble substances which in external appearance somewhat resembled sodium chloride—the familiar “salt” of commerce. Many substances were accordingly called salts without reference to their chemical character until chemistry had developed sufficiently to lead to the adoption of a technical nomenclature and classification based upon composition and structure. Insoluble substances were then no longer excluded. All soluble metallic compounds are called salts whose composition and general structure differ from those of the “acids” only in that the cations of the salts are metals, whereas the cations of the corresponding acids are hydrogen ions. Many insoluble metallic compounds of analogous composition and structure are also called salts. But the structure of acids composed of but two elements differs radically from that of acids composed of more than two elements, and many of the compounds called salts resemble each other less than they resemble compounds which are not salts. Such metallic chlorides, bromides and iodides as are called salts have a structure which is altogether different from that of the oxygen salts and thio-salts but which does not differ from the structure of the many chlorides, bromides and iodides which are not salts. The sulphides which are called salts differ decidedly in structure from the oxygen salts and the thio-salts but resemble perfectly the large number of sulphides which are not called salts, and their structure also agrees perfectly with that of the oxides.

The "salts," therefore, as that term is commonly employed, have no structural characteristics by which they may be recognized as a class. (See par. 52 and 61.)

Examples of various kinds of salts are presented in the following table:

SALTS.

Halides.	Sulphides.	Oxygen Salts.	Thio-salts.
KCl	K ₂ S	K(OC1)	
NaCl	Na ₂ S	K(OC1O ₂)	
LiCl	Li ₂ S	K ₂ (O ₂ SO)	
AgI	Ag ₂ S	Na(ON)	
HgCl ₂	HgS	Na(ONO)	
MgCl ₂	Hg ₂ S	Na(ONO ₂)	
CaCl ₂	CuS	Ca(O ₂ CO)	
PbCl ₂	ZnS	K ₂ (O ₂ SO ₂)	K ₂ (S ₂ SS ₂)
MnCl ₂	MnS	Na ₂ (O ₂ AsHO)	Na ₂ S ₂ AsHS
PbI ₂	PbS	Na ₂ (O ₂ CO)	Na ₂ (S ₂ CS)
AlCl ₃	Bi ₂ S ₃	Na ₃ (O ₃ Sb)	Na ₃ (S ₃ Sb)
FeCl ₃	Fe ₂ S ₃	Na(OSbO)	Na(SSbS)
SrBr ₂	NiS	Na ₃ (O ₃ SbO)	Na ₃ (S ₃ SbS)
AuCl ₃	Au ₂ S ₃	K(OMnO ₃)	
PtCl ₄	PtS ₂	K ₂ (O ₂ MnO ₂)	

Under these circumstances it is impossible to give a satisfactory general definition of salts. On the other hand, all classes of binary compounds, whether called salts or not, can be sharply defined. There is no doubt as to what constitutes a fluoride, chloride, bromide, iodide or sulphide. The only kinds of salts which may be satisfactorily defined are the oxygen salts and thio-salts.

72. The salts composed of but two elements are halides or sulphides of metals capable of performing the basic function in the formation of oxygen salts or of thio-salts. All such halides and sulphides, **if water-soluble**, are generally given the title of salts; but insoluble sulphides are rarely called salts.

Halides are the fluorides, chlorides, bromides and iodides of the metals. Cyanides are also called salts.

The name "halide" is derived from **hals**, salt, and **eidos**, like, and was given to the water-soluble compounds formed

by metals with the halogens on account of their external resemblance to the well known metallic oxygen salts. The term **halogen** means salt-former. It is derived from **hals**, salt, and **gennao**, make. It was applied to fluorine, chlorine, bromine and iodine because these elements form salt-like binary compounds with metals.

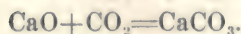
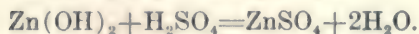
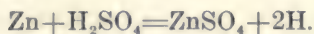
The student should note the great difference between a chloride such as KCl, containing negative Cl directly united to the metal, and a chlorate such as KClO₂, containing positive chlorine united to oxygen; and between a sulphide such as K₂S and a sulphate such as K₂O₂SO₂ or a thio-sulphate such as K₂S₂SS₂.

73. Oxygen salts are numerous. The inorganic oxygen salts are compounds consisting of basic elements (metals capable of performing the basic function in the formation of bases and salts) and acidic elements (capable of performing the acidic function in the formation of hydroxyl acids and of salts) united to each other by means of linking oxygen. The oxygen salts may contain, in addition, non-linking oxygen held in combination with the acidic element only, and may also contain hydrogen medietely combined with the acidic element by means of linking oxygen or immediately united to the acidic element.

Oxygen salts may be actually produced by or are hypothetically derived from the hydroxides and their structure is analogous to that of the hydroxyl acids. They may also be produced from basic and acidic oxides. The structure of the molecule of water may be said to be the type of the structure of oxygen salts and thio-salts.

When the (replaceable) hydrogen of a hydroxyl acid is exchanged for a metal the new compound thus formed is a salt.

The following equations illustrate the formation of oxygen salts:



Every oxygen salt has its corresponding acid, known or hy-

pothetical, from which it is derived and after which it is named. Should the corresponding acid be unknown "in its free state" the structure of a salt nevertheless serves to indicate theoretically the composition of the acid to which it corresponds and it is named accordingly.

The relation between acids and their salts is clearly seen in the following examples:

HONO_2 .	KONO_2 .
Nitric acid	Potassium nitrate.
$\text{H}_2\text{O}_2\text{SO}_2$.	$\text{K}_2\text{O}_2\text{SO}_2$.
Sulphuric acid.	Potassium sulphate.
$\text{H}_3\text{O}_3\text{PO}$.	FeO_3PO .
Phosphoric acid.	Ferric phosphate.
$\text{H}_2\text{O}_2\text{CO}$.	KHO_2CO .
Carbonic acid.	Potassium bicarbonate.

But many salts contain more than three elements, as, for instance, the double salts (par. 76) and the organic salts.

A **thio-salt** is one in which sulphur takes the place of all or a part of the oxygen.

The only negative element in an inorganic oxygen salt is the oxygen. In a thio-salt the negative element is sulphur, or it may contain oxygen as well as negative sulphur.

Thio-salts in which the acidic element is sulphur and which contain no oxygen may be composed of but two elements, as Na_2SS_4 and Na_2SS_2 .

74. Oxygen salts analogous to the acidic hydroxides of normal structure contain no oxygen except that which performs the linking function.

As the inorganic acidic hydroxides of normal structure have been called "ortho-acids," the salts corresponding to them have been called "ortho-salts." Compounds corresponding to H_4CO_4 are called ortho-carbonates, and kaolin, AlHSiO_4 , is called an ortho-silicate.

But the student is warned against assuming that the prefix "ortho" uniformly has that significance for the salts of H_3PO_4 are called ortho-phosphates, although they are meta-phosphates.

While salts corresponding to the acidic hydroxides of normal structure are sometimes called normal salts, the same term is used to designate salts formed by replacing all of the replaceable hydrogen of any acid whether that acid be an acidic hydroxide of normal structure or a meta-hydroxide. Thus K_2CO_3 is called a normal carbonate to distinguish it from the "bicarbonate," $KHCO_3$.

75. A primary salt is the salt formed when any acid exchanges but one of its hydrogen atoms for a basic element. All the salts of monobasic acids are necessarily primary salts.

Secondary salts are formed by the replacement of two of the replaceable hydrogen atoms of an acid by a basic element.

Tertiary salts are formed when three hydrogen atoms of acids are replaced by metal.

An **acid salt** is a salt still containing replaceable hydrogen.

A **basic salt** is one containing a greater proportion of the basic element than that corresponding to the replaceable hydrogen of the acid. These compounds are often represented as formed by salts with bases or with basic oxides, as shown by the formulas $(MgCO_3)_4 \cdot Mg(OH)_2$ and $(HgO)_2 \cdot HgSO_4$.

The following examples illustrate the application of the foregoing designations:

$NaNO_3$ is sodium nitrate. It is derived from HNO_3 and is a primary salt.

Na_2SO_4 is sodium sulphate derived from H_2SO_4 and a secondary salt.

$NaHSO_4$ is primary sodium sulphate, and an "acid salt" or a "bisulphate."

K_2CO_3 is secondary potassium carbonate derived from H_2CO_3 .

$KHCO_3$ is a primary salt, the so-called potassium bicarbonate, or "acid carbonate" of potassium.

$K_2C_2O_4$ is secondary potassium oxalate, derived from $H_2C_2O_4$.

It is often called "neutral potassium oxalate" and also "normal potassium oxalate."

KHC_2O_4 is primary potassium oxalate, and is also called "potassium acid oxalate" and "potassium binoxalate."

$\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$ is tertiary sodium citrate, or "neutral sodium citrate," or "tri-sodium citrate," derived from citric acid, $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$.

$\text{Na}_2\text{HC}_6\text{H}_5\text{O}_7$ is secondary sodium citrate, or "di-sodium—hydrogen citrate"—one of the acid citrates of sodium.

$\text{NaH}_2\text{C}_6\text{H}_5\text{O}_7$ is primary sodium citrate, or "sodium—di-hydrogen citrate"—another acid salt.

$\text{KHC}_4\text{H}_4\text{O}_6$ is primary potassium tartrate or "potassium acid tartrate," or "potassium bitartrate," commonly known as "cream of tartar."

$\text{KNaC}_4\text{H}_4\text{O}_6$ is a secondary salt and a double-salt. It is called a "neutral" salt, or a "normal salt." It is best to call it "potassium sodium tartrate." It is commonly known as Rochelle salt.

$\text{Ca}_3(\text{PO}_4)_2$ is tertiary calcium phosphate, or tri-calcium phosphate.

$\text{CaH}_4(\text{PO}_4)_2$ is an acid calcium phosphate.

CaHPO_4 is another acid calcium phosphate.

$\text{HOPbC}_2\text{H}_3\text{O}_2$ is a basic lead acetate derived from $\text{HC}_2\text{H}_3\text{O}_2$ and from the base $(\text{HO})_2\text{Pb}$.

FeH_2SO_5 is ferrous mono-meta-sulphate derived from H_4SO_5 , and is an "acid salt."

76. Double-salts are salts containing two basic elements instead of one. The alums contain one monovalent and one trivalent basic element or group:

$\text{AlK}(\text{SO}_4)_2$
Potassium alum.

$\text{AlH}_4\text{N}(\text{SO}_4)_2$
Ammonium alum.

Double-salts may be formed by "bibasic" acids, which are acids containing divalent anions and, therefore, two replaceable hydrogen atoms.

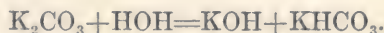
77. Reactions of salts on litmus. A water-soluble salt may have an acid, neutral or alkaline reaction on litmus, whether the salt is acid or basic or neither acid nor basic in structure.

A salt containing no hydrogen may have a neutral reaction if it is the salt of a strong base and a strong acid, or of a feeble base with a feeble acid; it may have an acid reaction if formed out of a strong acid with a feeble base; or an alkaline reaction if formed out of a strong base with a feeble acid.

A salt having an "acid structure" (par. 75) may nevertheless have an alkaline reaction, as, for instance, KHCO_3 .

A salt of basic structure may have an acid reaction, as, for instance, ferric subsulphate, $\text{Fe}_4\text{O}(\text{SO}_4)_5$. •

The action of water-soluble chemical compounds upon litmus is assumed to be in many cases influenced by hydrolytic changes. Hydrolysis, or hydrolytic metathesis (double decomposition), is a reaction in which one of the reagents is water. It is illustrated by:

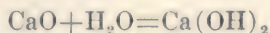


It is assumed that a water-solution made of K_2CO_3 always contains KOH and that its strongly alkaline reaction is due to the hydroxyl ions split off by ionization from KOH.

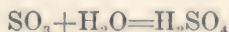
It is assumed that salts which do not undergo hydrolysis do not affect litmus or, in other words, are neutral to it, whereas salts which are hydrolysed turn blue litmus red if one of the products of the hydrolysis is a compound furnishing hydrogen ions, but turn red litmus blue if hydroxyl ions are split off.

When both hydrogen ions and hydroxyl ions are formed, as in the ionization of water, the liquid should be neutral.

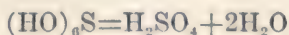
Students should be careful to keep in mind the differences between hydrolysis and ionization, and between the three kinds of reactions in which water is either a factor or a product. Water is a factor in the reactions:



and



and these reactions are called syntheses. A synthesis is the opposite of dissociation. Water is a product of dissociation in the reaction



which results when dilute sulphuric acid is "concentrated" by evaporation.

Ionization is the dissociation or splitting of a molecule into ions (which are not molecules); the dissociation of a molecule into two or more new molecules is a very different phenomenon; and hydrolysis is simply double decomposition or metathesis resulting from the interaction of two kinds of molecules upon each other, one of the reagents being water.

CHAPTER IV.

THE NOMENCLATURE OF INORGANIC CHEMICAL COMPOUNDS.

78. The nomenclature of inorganic chemical compounds is based upon the recognition of valence, chemical polarity and molecular structure.

The titles used are made up of systematically constructed substantives and adjectives.

The substantive nouns are derived from the names of the **negative** elements, ions or radicals. The adjectives are derived from the names of the **positive** elements, ions or radicals. But the names of the negative compound radicals of oxygen salts and thio-salts are primarily derived from the positive elements in those radicals.

79. The technical names of most of the inorganic compounds are based upon the assumption that the compounds named can be considered as being composed of **two radicals**, elemental or compound, one positive and the other negative. Any molecule, simple or complex, may be divided into two parts one of which consists of a relatively positive element or compound radical and the other of a relatively negative element or compound radical. Wherever the cleavage may be the hypothetically severed bonds must be equal numbers of positive and negative bonds. The molecule of di-meta-sulphuric acid may be written either H_2SO_4 or $(\text{HO})_2\text{SO}_2$; it may be regarded as composed of hydrogen and SO_4 or of hydroxyl and SO_2 . The molecule of acetic acid is



It may be divided into H_3C and COOH , or into $\text{H}_3\text{C.CO}$ and OH , or into $\text{H}_3\text{C.CO.O}$ and H (or $\text{H.C}_2\text{H}_3\text{O}_2$), according to

whether we desire to represent it as a compound of methyl and carboxyl, a compound of methyl and carbonyl with hydroxyl, or a compound of the ions H and O.C.CH_3 .

The ionization cleavage of KOH divides it into K and OH ; that of HOCl divides that molecule into H and OCl ; the ionization cleavage of KOCl splits it into K and OCl .

The technical names of inorganic chemical compounds generally agree with their hypothetical ionization cleavage, or with a division of the molecule into two radicals which division is analogous to that cleavage.

80. The **substantive nouns** are the generic titles of the several classes of compounds, according to composition and structure.

Binary compounds receive names ending in **-ide** (or in **-id** in accordance with a proposed spelling reform not generally adopted), and those names are always derived from the names of their negative elements. Thus the

Fluorides are named after fluorine,

Chlorides are named after chlorine,

Bromides are named after bromine,

Iodides are named after iodine,

Oxides are named after oxygen,

Sulphides are named after sulphur,

Phosphides are named after phosphorus,

and so on.

Thus a binary compound of calcium and sulphur is not called a calcide of sulphur but a sulphide of calcium, because sulphur is its negative element; but CaSS_4 is not a sulphide because it is **not a binary compound** since it contains two different kinds of sulphur—one atom of positive hexavalent sulphur and four atoms of negative, divalent, linking sulphur.

A compound of carbon and hydrogen, like H_4C , is not a hydride of carbon but a carbide of hydrogen; one of carbon and nitrogen is not a carbide but a nitride; ammonia is a hydrogen nitride; a compound of S and O is not a sulphide but an oxide; one of S and Se is not a selenide but a sulphide; one of Cl and Br is not a bromide but a chloride. (See par. 27.)

But the names **hydroxides** and **hydrosulphides** are con-

structed with the same endings that are used in naming binary compounds. Hydroxides are compounds of the negative compound radical hydroxyl united to a positive element or group, and hydrosulphides are compounds containing the negative compound radical HS.

Cyanides are compounds containing CN. Ferrocyanides, ferricyanides, and various other compounds containing negative compound radicals are named in a similar manner.

But oxygen salts and thio-salts are given names ending in **-ate** or **-ite**. The salts of any kind of sulphuric acid, for example, receive names ending in **-ate** while the salts of sulphurous acid have names ending in **-ite**.

The student should note that the name **hydroxide** as well as the name **oxide** is derived from the name of the negative element oxygen, and the name **hydrosulphide** as well as the name **sulphide** from the name of the negative sulphur; but the names **sulphate** and **sulphite** are derived from the positive sulphur in the negative compound radicals of those salts.

The endings **-ide**, **-ate** and **-ite** are, however, not sufficient for positive elements having a variable valence have more than one oxide, chloride, sulphate, sulphite, etc. We then use **adjectives** constructed out of the names of positive elements to make distinction between two or more compounds containing the same positive and negative elements, ions or radicals but in different proportions.

When the positive radical has but one valence it can form only one compound with any negative radical because negative radicals have a constant valence. There is in such a case no need of the use of adjectives. Thus, as silver has only one valence it can have only one chloride, one oxide, one nitrate, etc., and the names silver chloride, silver oxide, silver nitrate, etc., are sufficiently definitive.

If, however, we want to construct titles for the silver compounds which shall correspond **in form** to the titles used to designate the two or more compounds formed with any given negative radical by positive radicals of more than one valence, we use the ending **-ic** and construct an adjective with that ending from the latinic name of silver. Hence we would say argentic chloride, argentic oxide, etc. In the same way we

get such titles as calcic oxide, lithic bromide, aluminic chloride, etc.

When a positive element or radical has two combining values and consequently two corresponding sets of compounds, then the higher combining value is indicated by the ending **-ic** and the lower by **-ous**. Thus carbonic compounds are formed by C with the algebraic combining number $+4$ and carbonous compounds are those in which the C has a value of $+2$.

Basic iron with a valence of 3 is called ferric iron, and forms ferric compounds while basic iron with a valence of 2 is ferrous and forms ferrous compounds.

Mercuric compounds are formed by mercuric mercury having a valence of 2, while mercurous compounds are formed by mercurous mercury having a valence of 1.

When the positive element from which the title is derived has three different combining values and hence three corresponding sets of compounds, the ending **-ic** designates the highest combining value, **-ous** the middle value, and the prefix **hypo-** together with the ending **-ous** indicates the lowest combining value. Thus sulphuric compounds are those containing S having a combining number of $+6$, sulphurous compounds are formed by S having the combining number $+4$, and hypsulphurous compounds contain S with the combining number $+2$. Phosphoric compounds contain P with the combining number $+5$, the compounds formed by P with the combining number $+3$ are phosphorous, and those formed by P with the combining value $+1$ are hypophosphorous. Hyponitrous acid is HNO , nitrous acid is HNO_2 , and nitric acid is HNO_3 .

To distinguish between four sets of compounds formed by a positive element having four different combining values, the ending **-ic** is used together with the prefix **per-** to indicate the highest value, the ending **-ic** is used alone to indicate the second, the ending **-ous** for the third value, and the prefix **hypo-** together with the ending **-ous** to indicate the lowest algebraic plus value. Thus perchloric acid is HClO_4 , chloric acid is HClO_3 , chlorous acid is HClO_2 , and hypochlorous acid is HClO . Perchloric chlorine has the combining value $+7$, chloric chlorine $+5$, chlorous chlorine $+3$, and hypochlorous chlorine $+1$.

[The Cl of chlorides is negative Cl and has the value -1 .]

81. Nitrogen and manganese have more than four different combining values when in combination with oxygen.

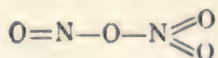
The recognized existence of N_2O , NO , N_2O_3 , NO_2 , and N_2O_5 shows that positive nitrogen may have the several algebraic combining numbers +1, +2, +3, +4 and +5.

Manganese forms $MnCl_2$, Mn_2O_3 , MnO_2 , $K_2Mn_2O_5$, K_2MnO_4 and $KMnO_4$. These formulas show that Mn can have the several values of +2, +3, +4, +6 and +7.

In such cases as these the endings **-ic** and **-ous** and the prefixes **hypo-** and **per-** are insufficient.

The **normal** combining values of positive nitrogen must be +1, +3 and +5 as indicated by its position in the periodic system of classification of the elements. The compounds NO and NO_2 are unsaturated molecules; they are very unstable; and they are compound radicals common to many compounds. The name **nitrosyl** is given to NO and the name **nitryl** to NO_2 ; both these names are unobjectionable. But NO is commonly referred to also by the name "nitric oxide" which is inconsistent with the name of nitric acid. The name of "nitrous oxide" is commonly applied to N_2O which is inconsistent with the name of nitrous acid. It would be quite consistent with our system to give N_2O the name of hyponitrous oxide, NO the name nitrosyl, N_2O_3 the name of nitrous oxide, NO_2 the name of nitryl, and N_2O_5 the name nitric oxide.

NO_2 is often called nitrogen "tetroxide" from the fact that at lower temperatures its composition is N_2O_4 . NO_2 is deep red brown, but N_2O_4 is colorless; this fact, together with the fact that with cold water it yields both nitric and nitrous acid, suggests the question whether it is not



instead of $(NO_2)_2$.

Basic manganous manganese has a valence of 2; basic manganic manganese has a valence of 3; acidic manganous manganese (as in potassium manganite, $K_2Mn_2O_5$) has a valence of 4; acidic manganic manganese (as in manganates) has a valence of 6; and permanganic manganese has a valence of 7.

[Basic and acidic properties and functions are opposite. When metals perform the basic function their valence is low;

they perform the acidic function when their valence is higher. Hence no serious confusion arises from the fact that the same adjective may be used to indicate different valences when the element is basic in one case and acidic in the other. Thus we experience no difficulty from the use of the term manganic sulphate in which the basic manganese has a valence of 3 and the term manganic acid in which the acidic manganese has a valence of 6; nor from the use of the names ferric nitrate containing basic trivalent iron and ferric acid containing acidic hexavalent iron. But we also have the name manganite for salts containing acidic manganese with a valence of 4, manganese dioxide for MnO_2 in which the Mn is neither basic nor acidic, and manganous chloride for MnCl_2 in which the valence of the manganese is 2.

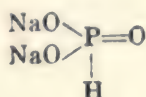
Ferrous basic iron has a valence of 2, but ferrites contain iron with a valence of 3, and that valence is also characteristic of compounds containing basic ferric iron. These anomalies serve to show that our system of chemical nomenclature is in some cases irregular, inconsistent and therefore in need of amendment.]

82. In the nomenclature of **salts** the negative ion is identified by the endings **-ate** and **-ite** and the prefixes **hypo-** and **per-**. The ending **-ate** is used to designate the salt of an **-ic** acid, the ending **-ite** to designate the salt of an **-ous** acid, a term having the prefix **hypo-** as well as the ending **-ite** is used to designate the salt of an acid containing the acidic element with a lower combining value than that which it has in an **-ite**, and a term having the prefix **per-** as well as the ending **-ate** is used in naming a salt in which the acidic element has a higher combining value than that which it exercises in salts given names ending in **-ate**.

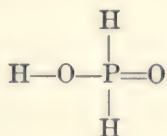
Thus nitric acid forms nitrates and sulphuric acid sulphates; but nitrous acid forms nitrites and the salts of sulphurous acid are called sulphites. Hyponitrous acid forms hyponitrites, hypochlorous acid hypochlorites and hyposulphurous acid (H_2SO_2) hyposulphites. Perchloric acid forms perchlorates, per-iodic acid per-iodates, and permanganic acid permanganates.

83. The phosphorus in H_3PO_4 has a valence of 5; but its

valence is 5, also in Na_2PHO_3 and in HPH_2O_2 . We call H_3PO_4 a **phosphoric** compound because the algebraic combining number of the P in that compound is +5; we call $\text{Na}_2\text{O}_2\text{PHO}$ a **phosphite** because its structure is

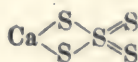


which shows that the P has four positive bonds united to the oxygen atoms and one negative bond by which it holds the hydrogen atom, and the sum of +4 and -1 is +3; and we call HPH_2O_2 **hypo-phosphorous** acid because its structure is



showing that the P in this compound has 3 positive bonds uniting it to the oxygen and 2 negative bonds by which it holds two hydrogen atoms and the sum of +3 and -2 is +1.

We can at once see that CaS_5 can not be a sulphide, for all of the S in any sulphide must be divalent and every atom of it have the algebraic combining number -2. We call it a **sulphate** because its structure is



and the central sulphur atom has a valence of 6 and the algebraic combining number +6, while all the other sulphur atoms have each a valence of 2 and the algebraic combining number -2, for those four sulphur atoms perform the same function in the CaSS_4 that the oxygen atoms perform in CaSO_4 .

It will be seen from the foregoing that in many cases (as, for instance, in naming nearly all the carbon compounds) the style of nomenclature generally used for compounds is insufficient. In all cases where it is applicable it is governed by the algebraic sum of the positive and negative bonds, but not

by the valence (as will be seen clearly from the nomenclature of the hypophosphites and phosphites, arsenites, etc.)

84. Various other prefixes are used in the technical nomenclature of inorganic compounds. For the convenience of the student the commonly employed prefixes are given in this table with the meaning of each:

(a) Prefixes derived from Greek numerals:

Mono or **mon**, meaning one, single or once.

Di or **dis**, meaning two or twice.

Tri or **tris**, meaning three or thrice.

Tetra, meaning four.

Penta, meaning five.

Hexa, meaning six.

Hepta, meaning seven.

Octo, meaning eight.

Deka, meaning ten.

Dodeka, meaning twelve.

(b) Prefixes derived from Latin numerals:

Un or **uni**, meaning one or single.

Duo, **bi**, **bin**, or **bis**, meaning two or twice.

Ter or **tri**, meaning three or thrice.

Quadri or **quadra**, meaning four.

Quinque or **quinqui**, meaning five.

Sexa or **sexi**, meaning six.

Septi or **sept**, meaning seven.

Octo or **octi**, meaning eight.

(c) Other prefixes:

Hypo, meaning under, lower or below.

Sub, meaning under, lower or below.

Per, meaning thorough, through or to the full extent.

Meta, meaning altered, different, after or beyond.

Para, meaning changed, different or altered.

Ortho, meaning straight, regular, common, usual or original.

Pyro, meaning as produced by fire or high heat.

Thio, from **theion** (sulphur), meaning containing sulphur.

The following illustrations will suffice to render clear the mode of employment of some of the foregoing prefixes:

A monochloride is a chloride containing but one chlorine atom; a dioxide is an oxide containing two oxygen atoms; a tri-iodide contains three iodine atoms; a tetroxide contains four oxygen atoms; a pentafluoride contains five fluorine atoms; a hexachloride contains six chlorine atoms; a heptoxide contains seven oxygen atoms in each molecule.

A bicarbonate contains twice as large a proportion of the carbonate radical CO_3 as a carbonate contains in proportion to the basic element, as shown by the molecular formulas KHCO_3 and K_2CO_3 , in which K is the basic element.

Subsulphate of mercury contains a smaller quantity of the sulphate radical SO_4 in proportion to the mercury than the sulphate of mercury contains. Subnitrate of bismuth is a name given to OBiNO_3 , containing the NO_3 only once, while bismuth nitrate is $\text{Bi}(\text{NO}_3)_3$.

A thiocarbonate is a carbonate in which the oxygen is in part or wholly replaced by sulphur. A thiosulphate is a sulphate containing a larger proportion of sulphur than is contained in the common sulphates, some or all of the oxygen of the sulphate being replaced by sulphur atoms. Thus, sulphate of calcium is CaSO_4 , while thiosulphate of calcium is CaSS_4 , and other calcium thiosulphates are CaSO_3S , CaSO_2S_2 , and CaSOS_3 .

The name orthophosphoric acid means the common or ordinary phosphoric acid. The prefix **ortho** does not indicate its composition, but the ending **ic** indicates that the phosphorus in it has the combining number +5, which is the highest of the three positive algebraic combining numbers possible to phosphorus. The formula for orthophosphoric acid is H_3PO_4 , or $(\text{HO})_3\text{PO}$. A normal phosphoric hydroxide is, of course, $(\text{HO})_5\text{P}$. Accordingly, it is evident that orthophosphoric acid is a mono-meta-acid, and the name mono-meta-phosphoric acid is sufficient to indicate the structure of the compound or its true molecular formula. The glacial phosphoric acid commonly called meta-phosphoric acid has the formula HPO_3 , or HOPO_2 ; it is therefore a di-meta-acid [$(\text{HO})_5\text{P}$, or H_5PO_5 with two molecules of water split off from it, leaving HPO_3].

What is commonly called pyrophosphoric acid is a phosphoric acid produced by heating orthophosphoric acid, and a pyrophosphate is obtained by heating the corresponding orthophosphate. The common phosphate of sodium is Na_2HPO_4 ; it is accordingly disodium monohydrogen mono-meta-phosphate. But the pyrophosphate of sodium is $\text{Na}_4\text{P}_2\text{O}_7$.

The name pyrophosphate does not indicate the composition, whereas the explicit technical term sodium tri-meta-di-phosphate at once tells the whole story of its structure. It tells us that the acidic element in the compound is phosphoric phosphorus. The term diphosphate tells us that it contains two phosphorus atoms. And the term tri-meta informs us that it differs by three molecules of water from the normal structure of two molecules of sodium phosphate added together. Two molecules of normal phosphoric hydroxide added together would make the formula $\text{H}_{10}\text{P}_2\text{O}_{10}$. Three molecules of water split off from that formula would leave $\text{H}_4\text{P}_2\text{O}_7$. The sodium salt corresponding to $\text{H}_4\text{P}_2\text{O}_7$ is $\text{Na}_4\text{P}_2\text{O}_7$.

Borax is a sodium penta-meta-tetra-borate, because it is the sodium salt formed out of a boric acid resulting from the splitting off of five molecules of water from four molecules of normal boric hydroxide. It is called a tetra-borate because it contains four boron atoms. A borate must, of course, be formed from boric acid, and boric boron has a valence of 3. Normal boric hydroxide is accordingly $(\text{HO})_3\text{B}$ or H_3BO_3 . Four molecules of H_3BO_3 would be $\text{H}_{12}\text{B}_4\text{O}_{12}$, and after splitting off five molecules of water from $\text{H}_{12}\text{B}_4\text{O}_{12}$, we would have $\text{H}_2\text{B}_4\text{O}_7$ left, which is penta-meta-tetra-boric acid, and the sodium salt of it is accordingly $\text{Na}_2\text{B}_4\text{O}_7$.

From the facts stated in the foregoing paragraphs, the student will see that hypobromous chloride would be BrCl ; hypochlorous oxide must be Cl_2O ; hypochlorous acid must be HOCl ; potassium hypochlorite is KOC ; and calcium hypochlorite $\text{Ca}(\text{ClO})_2$.

Hypophosphorous oxide must be P_2O . Hypophosphorous acid may be either HOP or it may be HOPH_2O , in which the student can readily see that the algebraic combining number of the phosphorus is still $+1$.

Phosphorous oxide must be P_2O_3 ; phosphorous chloride must

be PCl_3 ; and phosphorous acid may be either $(\text{HO})_3\text{P}$ or HPO_2 , or it may be even $(\text{HO})_2\text{PHO}$, for in all of these formulas of acids it is clearly seen that the phosphorus atom has an algebraic combining number of $+3$.

The student can readily see at once that H_5PO_5 , H_3PO_4 , HPO_3 , and $\text{H}_4\text{P}_2\text{O}_7$ must all be different kinds of phosphoric acid, because in every one of them the phosphorus atom clearly has an algebraic combining value of $+5$.

Upon examination of the formulas H_6SO_6 , H_4SO_5 , and H_2SO_4 , it is seen that these formulas all represent different kinds of sulphuric acid, the first being normal sulphuric hydroxide, the second mono-meta-sulphuric acid, and the third di-meta-sulphuric acid, because in all of them the sulphur atom is seen to have a combining value of $+6$.

The formula CaH_4SO_6 evidently represents a calcium sulphate derived from normal sulphuric hydroxide. CaH_2SO_5 is a sulphate derived from the mono-meta-sulphuric acid, and CaSO_4 is calcium di-meta-sulphate. FeH_2SO_5 is ferrous mono-meta-sulphate, which is common ferrous sulphate, or green vitriol, minus its water of crystallization.

$\text{FeH}_2\text{SO}_5 + 6\text{H}_2\text{O}$ is the hexahydrate of ferrous mono-meta-sulphate.

A deka-borate is a borate containing ten boron atoms. The deka-hydrate of sodium di-meta-sulphate is $\text{Na}_2\text{SO}_4 + 10\text{H}_2\text{O}$. A dodeka-hydrate contains twelve molecules of water.

CHAPTER V.

CHEMICAL NOTATION.

85. Chemical notation is a system of representing the chemical elements and their respective mass units of combination by means of symbols, and the definite chemical compounds by corresponding combinations of the symbols.

86. Each chemical element is represented by its own specific **symbol**. That symbol consists of one or two letters. If the symbol consists of but one letter then that is the initial letter of the latinic or some other name of the element. But as a considerable number of elements have names beginning with the same letter an additional letter is employed in many such cases in order to give to each element its own distinctive symbol. Thus C is the symbol for carbon, H for hydrogen, N for nitrogen, O for oxygen and S for sulphur; but as C is the symbol for carbon, Cd is the symbol chosen to represent cadmium, Cs stands for cæsium, Ca for calcium, Ce for cerium, Cl for chlorine, Cr for chromium, Co for cobalt, Cb for columbium, and Cu for copper (from the latin cuprum).

87. But the symbol of a chemical element stands for more than the name and identity of it. It means also its specific mass unit of chemical combination, or what is known as its atom. Thus H stands for hydrogen and at the same time for one atom of hydrogen and for the mass of that atom which is the combining weight of the element.

88. Symbolic formulas consist of symbols with or without numerals. A single symbol alone is not a formula; but a symbol with a numeral before or after it is one, and any combination of two or more symbols, with or without numerals, is also a symbolic formula. Thus H and O are both symbols but not formulas, while 2H, or 2O, H_2 , O_2 , O_3 , HO, H_2O , $HNOH$, $3H_2O$, and H_2O_2 are formulas.

89. Symbolic formulas may represent either free atoms, compound radicals, empiric statements of composition, molecules, or combinations of molecules.

2H represents two uncombined atoms of hydrogen.

3H represents three uncombined atoms of hydrogen.

3O represents three uncombined atoms of oxygen.

4P represents four uncombined atoms of phosphorus.

H_2 represents two atoms of H combined into one molecule.

O_2 represents two atoms of O combined into one molecule.

O_3 represents three atoms of O combined into one molecule.

P_4 represents four atoms of P combined into one molecule.

HO represents the compound radical called hydroxyl.

CH_3 or H_3C represents the compound radical called methyl.

NO represents the compound radical called nitrosyl.

NO_2 represents the compound radical called nitryl.

CO represents the compound radical called carbonyl.

CaO represents one molecule of calcium oxide.

2CaO represents two molecules of calcium oxide.

H_2O represents one molecule of water.

HOH represents one molecule of water or hydrogen hydroxide.

O_2 represents one molecule of oxygen.

3O_2 represents three molecules of oxygen.

2O_3 represents two molecules of ozone.

$\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2$ represents one molecule of lead acetate.

$3\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2$ represents three molecules of lead acetate.

$\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2 + 3\text{H}_2\text{O}$, or $\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot 3\text{H}_2\text{O}$, represents a combination of one molecule of lead acetate with three molecules of water.

90 The **numerals** used in symbolic formulas are of two kinds—large and small.

Both are used as multipliers or co-efficients and apply to the symbols or formulas according to their position.

Large numerals placed in front of single symbols indicate the number of atoms of the respective elements represented by them. Thus 3Fe means three atoms of iron. But a large numeral is never used in front of a symbol alone except when the element represented by that symbol is uncombined.

Large numerals in front of atomic groups or formulas multiply those whole groups or formulas, whether they represent

saturated or unsaturated molecules, **up to the next following period**, but not beyond that period. Thus 3H_2 means 3 times H_2 ; $3\text{H}_2\text{O}$ means 3 times H_2O ; 2NO means twice NO ; and $5\text{Na}_2\text{CO}_3$ means 5 times Na_2CO_3 . But in $2\text{K}_2\text{CO}_3 \cdot 3\text{H}_2\text{O}$ the large figure 2 multiplies only the K_2CO_3 .

Small numerals placed after the symbols, and usually a little below the line as in the formulas here printed, multiply only the symbols to which they are appended. Thus the formula H_2 means H taken twice; but that formula also means that the two hydrogen atoms are not free atoms but in chemical combination with each other whereas 2H means two atoms of hydrogen **not** in combination.

When, however, the H_2 is a part of a formula, as in H_2SO_4 , then the two hydrogen atoms are not in combination with each other but with one or more other atoms in the group.

The formula Al_2O_3 means a molecule composed of 2 atoms of Al united to 3 atoms of O.

91. Brackets are used in formulas when groups of two or more symbols are to be multiplied by the numerals given. Thus $\text{Fe}(\text{OH})_3$ means one atom of Fe in chemical combination with 3 times the group OH; $\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2$ means one atom of Pb in combination with twice the group $\text{C}_2\text{H}_3\text{O}_2$; $(\text{H}_4\text{N})_2\text{SO}_4$ means twice H_4N combined with the group SO_4 ; $\text{Fe}_2(\text{SO}_4)_3$ means 2 atoms of iron in combination with three groups of SO_4 ; and $3[\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot 3\text{H}_2\text{O}]$ means 3 times the molecular combination consisting of one molecule of $\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2$ and 3 molecules of H_2O .

92. Periods used in formulas serve to separate distinct groups of symbols (or atomic groups) from each other. Thus the formula $\text{H}_3\text{C} \cdot \text{CO} \cdot \text{OH}$, or $\text{HO} \cdot \text{OC} \cdot \text{CH}_3$ means a molecule composed of three distinct groups, or radicals, namely H_3C , CO and OH.

93. Empiric formulas are formulas indicating in the simplest terms the **relative** numbers of atoms of each element contained in a compound—not the actual or **absolute** numbers.

The empiric formula for acetic acid is CH_2O . It simply expresses the fact that for each carbon atom in the compound there are two hydrogen atoms and one oxygen atom. But

CH_2O is also the empiric formula for formaldehyde and at the same time the molecular formula for that compound.

94. Molecular formulas show the actual number of atoms of each kind which make up one molecule or **the** molecule of the compound.

The molecular formula for acetic acid is not CH_2O but $\text{C}_2\text{H}_4\text{O}_2$, or $\text{HC}_2\text{H}_3\text{O}_2$, or $\text{H}_3\text{C}.\text{CO}.\text{OH}$, for the vapor density of acetic acid proves that its molecular weight must be the sum of the weights of two carbon atoms, four hydrogen atoms and two oxygen atoms.

The formula $\text{C}_2\text{H}_4\text{O}_2$ may be called an empiric-molecular formula because while it shows the actual numbers of atoms of each of the three component elements it conveys no idea of the structure or character of the compound.

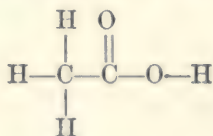
The formula $\text{HC}_2\text{H}_3\text{O}_2$ is the commonly used molecular formula for acetic acid, and shows that it is composed of the two ions H and $\text{C}_2\text{H}_3\text{O}_2$. It may be called its ionic formula. The first H of the $\text{HC}_2\text{H}_3\text{O}_2$ is the "replaceable hydrogen" of the acid.

The formula $\text{H}_3\text{C}.\text{CO}.\text{OH}$, or $\text{HO}.\text{CO}.\text{CH}_3$, is a structural formula of acetic acid.

95. Constitutional or structural formulas show more or less clearly the distinct atomic groups recognized as composing the molecule. Thus the constitutional formula for acetic acid, $\text{HO}.\text{CO}.\text{CH}_3$, shows that it is composed of hydroxyl (OH or HO), carbonyl (CO), and methyl (CH_3 or H_3C).

96. A graphic structural formula shows the assumed interatomic linking, or the grouping of the atoms, or their relative positions.

The graphic structural formula of acetic acid is



Graphic formulas show clearly the bonds or valence units of all the respective component atoms. *All such formulas conform to the accepted doctrines of valence.*

The carbon atoms are shown to have four bonds or valence units indicated by the four straight lines connecting each carbon atom with the atoms of hydrogen or oxygen or the other atom of C; each hydrogen atom is seen to have one bond, and each oxygen atom two bonds. The first carbon atom holds 3 hydrogen atoms and is besides connected by its fourth bond to the second carbon atom which holds one oxygen atom by 2 bonds and is connected to the second oxygen atom by 1 bond while the second oxygen atom holds by its second bond the last hydrogen atom.

Graphic structural formulas are necessary to explain the structure of numerous organic chemical compounds.

97. How to write the molecular formulas of binary compounds.—

The valence units presented by both elements must be the same number.

Thus, if the atom of the positive element has the same valence as that of the negative element, one atom of each will be required. No numerals are then used. The formula BN stands for boron nitride, for boron and nitrogen are both triads; magnesium oxide is MgO because magnesium and oxygen have the same valence; hydrogen chloride is HCl for the hydrogen atom and the chlorine atom (in all chlorides) each has one bond.

A symbol without any numeral stands for one atom. Hence the figure 1 is never written in any chemical formula.

It is evident that the number of valence units or bonds presented by each element, in order to be the same number as of the other, must be a common multiple of the valences of both. If the valence of the positive element is 2 and that of the negative element 3, then the number of bonds or units of valence from each must be 2×3 or 6; three atoms of any diad have together a total of 6 valence units, and two atoms of a triad will be required to make 6 units. Thus the molecular formula of zinc phosphide must be Zn_3P_2 .

If the valence of the positive element is 5 and that of the negative element 2, then the total bonds from each must be 10. Hence the molecular formula of phosphoric oxide must be P_2O_5 .

Therefore, when the valence of each element differs from that of the other—

Write first the symbol of the positive element and then the symbol of the negative element. Then multiply the symbol of each element by the valence of the other.

To write the formula for aluminum oxide first write down AlO ; then, as the valence of Al is 3 write the figure 3 after the O ; and as the valence of O is 2 write the figure 2 after the Al . The formula will then be Al_2O_3 which is correct.

To write the molecular formula of aluminum chloride, first write down AlCl ; then as the valence of Al is 3 and that of the Cl is 1, write the figure 3 after the Cl . It is not necessary to write the figure 1 after the Al . The formula will, therefore, be AlCl_3 .

But if the valences of the two component elements are both even numbers, or divisible by 2, then the number of valence units from each must be **the least common multiple** of the numbers expressing their respective valences. Thus the molecular formula for carbonic oxide is not C_2O_4 but CO_2 ; the molecular formula for sulphuric oxide is not S_2O_6 but SO_3 .

[These rules apply only to the writing of the molecular formulas of true binary compounds—those in which each and every atom of one of the elements is united directly to each and every atom of the other element.

They do not apply to formulas for compounds of two elements in which two or more atoms of one and the same element are united to each other, as, for instance, to the formulas H_2O_2 , H_2S_2 , S_2I_2 , Fe_2Cl_6 , S_2O_7 , CaSS_4 , K_2SS_2 , etc.

H_2O_2 is $\text{H}-\text{O}-\text{O}-\text{H}$, H_2S_2 is $\text{H}-\text{S}-\text{S}-\text{H}$, S_2I_2 is $\text{I}-\text{S}-\text{S}-\text{I}$, Fe_2Cl_6 is $(\text{FeCl}_3)_2$, in S_2O_7 two of the oxygen atoms are united directly to each other, in CaSS_4 one of the sulphur atoms is directly united to all the other sulphur atoms while only two of them are united to the calcium, and in K_2S_3 all of the sulphur atoms are connected to each other while only two of the sulphur atoms are united to the potassium, $\text{K}-\text{S}-\text{S}-\text{S}-\text{K}$.]

98. How to write the molecular formulas for compounds of two ions the respective valences of which are known but which are not binary compounds.—*First write the two ions, placing*

the positive before the negative ion; then multiply each ion (or radical) by the valence of the other.

Here, too, the numeral 1 is never written, and when both ions have the same valence neither of them is to be multiplied. (See par 97.)

The molecular formula for tri-calcium phosphate is $\text{Ca}_3(\text{PO}_4)_2$ because the valence of calcium is 2 and that of PO_4 is 3. The valence of PO_4 is 3 because the P in all phosphates has a valence of 5 and the valence of the O is 2, and the difference between 5 and 4×2 is 3. Hence 3 of the oxygen bonds in each group of PO_4 must be available for combination with other atoms so that the valence of PO_4 is 3.

The algebraic sum of the bonds of the positive ion must be the same as the algebraic sum of the bonds of the negative ion in any compound.

If then the positive bonds are designated by the plus sign (+) and the negative bonds by the minus sign (—), all the bonds added together algebraically make the sum of zero (0).

99. All true molecular formulas are interatomic systems with but one unbroken linkage.

Chemical compounds which have more than one system of inter-atomic linking are not molecules, but combinations of more than one kind of molecules, or are compounds distinctly different from those that have but one system of atomic linking in accordance with atomic valence.

100. Molecular formulas of the fluorides, chlorides, bromides and iodides.—These are easily written because the algebraic combining number of the negative ions of all of the compounds named is —1. Hence the number of atoms of F, Cl, Br or I contained in the molecule is the number expressing the combining value of the positive ion. Thus the halides of monovalent positive ions contain 1 atom of the halogen, those of divalent ions 2, those of trivalent ions 3, of tetravalent ones 4, those of pentavalent positive ions 5, and the molecules of the halides of hexavalent positive ions contain 6 atoms of the halogen.

Whenever any two of the elements F, Cl, Br and I form binary compounds with each other the element having the greater atomic mass and, therefore, found below the other in

the periodic table (p. 191) constitutes the positive element. Hence only one atom of that element can enter into the formation of the compound. The valence of that element expresses the number of atoms required of the other or negative element. This view is warranted by the fact that the valence of any negative ion is invariable. BrCl , ICl , IBr , ICl_3 and IF_5 are known to exist.

The known halides of sulphur include S_2Cl_2 , S_2I_2 , SCl_2 , SCl_4 and SI_6 . Such molecules as S_2Cl_2 and S_2I_2 are assumed to contain the sulphur atoms linked directly to each other: Cl-S-S-Cl and I-S-S-I . The SCl_2 is hyposulphurous chloride, SCl_4 is sulphurous chloride, and SI_6 is sulphuric iodide.

101. Molecular formulas of sulphides and oxides. Oxides and sulphides of normal structure have the following composition: Those of monovalent positive ions contain one oxygen atom or sulphur atom united to the positive ion taken twice, as shown in Ag_2O , Hg_2S , and $(\text{H}_4\text{N})_2\text{S}$; those of divalent ions contain one atom of oxygen or sulphur united to the positive ion taken once, as shown in MgO , FeS and CO ; the oxides and sulphides of trivalent, pentavalent and heptavalent ions follow the rule that the positive ion must be multiplied by the combining value of the negative ion and the negative ion must be multiplied by the combining value of the positive ion, as shown in Fe_2O_3 , As_2S_3 , Bi_2O_5 , P_2O_5 , Sb_2S_5 and Cl_2O_7 . The oxides and sulphides of tetravalent ions contain two atoms of oxygen or sulphur to the positive ion taken once, as shown in CO_2 , SO_2 and CS_2 ; those of hexavalent ions contain the positive ion united to three atoms of oxygen or sulphur as in SO_3 , CrO_3 ; and the oxides of ruthenium and osmium are RuO_4 and OsO_4 .

102. Nitrides, phosphides, arsenides and antimonides are the compounds of negative N, P, As and Sb, all of which have the algebraic combining number -3 . Thus we have H_3N , H_3P , H_3As , H_3Sb , Zn_3P_2 , Cu_3As_2 , NiAs , etc.

103. Carbides and silicides of normal structure are represented by H_4C and H_4Si . Calcium carbide, CaC_2 , may be assumed to have the structure



104. Cyanides are compounds containing the compound radical CN called cyanogen, having the algebraic combining number -1 . The cyanogen group in cyanides may be represented as $-C\equiv N$, and the whole group may be likened to a halogen. Thus potassium cyanide is KCN, zinc cyanide is $Zn(CN)_2$, ferric cyanide is $Fe(CN)_3$, etc.

Isocyanides are assumed to contain the group $-N\equiv C$, which also has the algebraic combining number -1 . Silver isocyanide is AgNC while silver cyanide is AgCN.

The gas called cyanogen is represented as $N\equiv C-C\equiv N$ in which both of the nitrogen atoms have the combining value -3 while one carbon atom must have the value $+4$ and the other the value $+2$.

105. The molecular formulas of **hydroxides** of normal structure are easily written since the combining number of the group OH is -1 . Thus we have LiOH, ClOH, $Ba(OH)_2$, $S(OH)_2$, $Al(OH)_3$, $B(OH)_3$, $N(OH)_3$, $Sn(OH)_4$, $S(OH)_4$, $P(OH)_5$, $S(OH)_6$.

The molecular formulas of metahydroxides differ from those of the hydroxides of normal structure by $(HOH)_n$. A mono-meta-hydroxide contains one oxygen atom less than the number contained in the hydroxide of normal structure; a di-meta-hydroxide contains two oxygen atoms less; a tri-meta-hydroxide, three oxygen atoms less, etc. Thus normal sulphuric hydroxide is $(HO)_6S$, or H_6SO_6 ; sulphuric mono-meta-hydroxide is H_4SO_5 ; sulphuric di-meta-hydroxide is H_2SO_4 . As sulphuric sulphur is a hexad its hydroxide of normal structure must contain 6 oxygen atoms; its mono-meta-hydroxide contains 5; and its di-meta-hydroxide 4 oxygen atoms. The number of hydrogen atoms must be the difference between the number of bonds of the oxygen atoms and the number of positive bonds of the third element.

When a metahydroxide is formed out of more than one molecule of the hydroxide of normal structure it is still easy to write its molecular formula provided its name is given in full so that we may know the number of molecules of normal structure from which the metahydroxide is derived as well as the number of oxygen atoms removed.

Penta-meta-disulphuric acid must be $H_2S_2O_7$, for a disul-

phuric acid must contain two sulphur atoms as indicated by the prefix **di-** and the meta-acid referred to is, therefore, derived from two molecules of sulphuric hydroxide of normal structure $2 \text{H}_6\text{SO}_6$ (or $\text{H}_{12}\text{S}_2\text{O}_{12}$), and the double prefix **penta-meta** informs us that five oxygen atoms are removed (or 5 molecules of water formed by splitting off 10 hydrogen atoms and 5 oxygen atoms), leaving $\text{H}_2\text{S}_2\text{O}_7$.

Chromic acid must contain acidic chromium with a combining value of +6; a di-chromic acid must contain two such chromium atoms. Hence penta-meta-dichromic acid must be $\text{H}_2\text{Cr}_2\text{O}_7$.

Common perchloric acid is tri-meta-perchloric hydroxide, HClO_4 .

Common chloric acid is di-meta-chloric hydroxide, HClO_3 .

Hypochlorous acid is normal hypochlorous hydroxide, HOCl , or HClO .

Common sulphuric acid is di-meta-sulphuric hydroxide, H_2SO_4 .

The sulphuric acid from which ferrous sulphate (FeH_2SO_5) and zinc sulphate (ZnH_2SO_5) are derived is mono-meta-sulphuric hydroxide, H_4SO_5 .

Common nitric acid is nitric-di-meta-hydroxide, HNO_3 .

Common phosphoric acid (ortho-phosphoric acid) is phosphoric mono-meta-hydroxide, H_3PO_4 .

"Glacial phosphoric acid" (commonly called "meta-phosphoric acid") is phosphoric di-meta-hydroxide, HPO_3 .

Pyrophosphoric acid is tri-meta-diphosphoric hydroxide, $\text{H}_4\text{P}_2\text{O}_7$.

Borax, $\text{Na}_2\text{B}_4\text{O}_7$, is derived from penta-meta-tetraboric acid.

Boric acid, H_3BO_3 is the boric hydroxide of normal structure.

The so-called "ortho-carbonates" are derived from carbonic hydroxide of normal structure, H_4CO_4 .

Common carbonates are derived from carbonic mono-meta-hydroxide, H_2CO_3 .

KIO_4 is potassium tri-meta-periodate.

K_5IO_7 is a mono-meta-periodate.

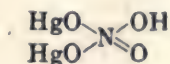
Ag_3IO_5 is a di-meta-periodate.

More complex meta-compounds are: $\text{Ag}_4\text{I}_2\text{O}_9$, $\text{Zn}_4\text{I}_2\text{O}_{11}$, $\text{K}_2\text{B}_6\text{O}_{10}$, $\text{K}_2\text{B}_{10}\text{O}_{16}$, $\text{K}_2\text{B}_{12}\text{O}_{19}$, $\text{Na}_2\text{W}_4\text{O}_{13}$ and $\text{Na}_{10}\text{W}_{12}\text{O}_{41}$.

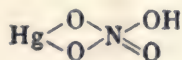
Aluminum meta-hydroxide is OAlOH . Ferric meta-hydroxide is OFeOH . Mono-meta-di-ferric hydroxide is $(\text{HO})_4\text{Fe}_2\text{O}_5$, and tri-meta-tetra-ferric hydroxide is $(\text{HO})_6\text{Fe}_4\text{O}_9$.

Each of the meta-compounds referred to here has one unbroken system of atomic linking which the student may profitably trace.

106. Many so-called basic salts may be seen to be probably derived from or related to the meta-hydroxides. One of the "basic mercurous nitrates" represented as Hg_2OHNO_3 is probably a mono-meta-nitrate:



One of the so-called "basic mercuric" nitrates is probably also a mono-meta-nitrate:



Several of the so-called basic salts may be seen to be derived from normal metallic hydroxides by the exchange of part of the hydroxyl for an acid-radical, as, for instance, the so-called subacetate of lead which is $\text{HOPbC}_2\text{H}_3\text{O}_2$ and differs from HOPbOH by the exchange of one hydroxyl group for the acetate radical $\text{C}_2\text{H}_3\text{O}_2$.

107. The order in which the symbols should be placed in chemical formulas is an important question.

The molecular formula for potassium chloride may be written KCl or it may be written ClK . Both formulas unmistakably mean potassium chloride.

The molecular formula for potassium hydroxide may be written in six different ways each of which would represent that compound and could not represent anything else; KOH , HOK , OHK , OKH , KHO and HKO must all be understood to be molecules composed of one atom of each of three elements, K, O and H, and such molecules can only be potassium hydroxide.

The molecule of nitric acid may be written HNO_3 , NO_3H , O_3HN , O_2NOH , HONO_2 , HOOON , and in several other ways.

Sulphuric acid may be represented by H_2SO_4 , or $(\text{HO})_2\text{SO}_2$, or $\text{H}_2\text{O}_2\text{SO}_2$, $\text{SO}_2(\text{OH})_2$, etc.

The molecular formulas for salts may be of various styles.

It is desirable to observe some definite system or rule governing the order in which the symbols and the distinct atomic groups recognized as components of the molecule shall be placed in the symbolic formulas. Unfortunately there is no generally recognized rule.

The following rules have been recognized to a great extent:

The symbols of atoms in direct combination with each other should, as far as practicable, be placed beside each other.

The only formulas for potassium hydroxide which conform to this rule are KOH and HOK, because the oxygen atom holds both of the other atoms in direct union with itself in accordance with the doctrine of valence and the conception of atomic linking based upon it.

Positive ions should be written before the negative ions as far as practicable.

A recognition of this rule would result in discarding such formulas as ClK and HOK, and would cause the adoption of KCl and KOH as the proper formulas.

In all binary compounds formed by metals with non-metallic elements the metal is the positive element or ion and the non-metallic element is the negative ion.

The hydrogen is the positive ion or element in any binary compound it forms with any non-metallic element. The commonly employed formulas CH_4 , NH_3 and PH_3 are inconsistent with the commonly employed formulas H_2O , H_2S and HCl . The formulas H_4C , H_4Si , H_3N , H_3P , H_3As , H_3Sb , H_2O , H_2S , H_2Se , H_2Te , HF , HCl , HBr and HI are consistent with each other.

108. When certain atomic groups are recognized as components of a molecule the formulas should be written in such a way as to indicate that fact. At the same time the principles underlying the rules given in par. 107 should be observed as far as may be consistent with this rule.

This statement is equivalent to saying that molecular formulas should as far as practicable show the assumed structure of the compounds they represent. Graphic structural formulas are as complete pictures of interatomic linking as can be produced;

but their usefulness is limited by the fact that they require too much time and labor. Simpler structural formulas are possible in numerous cases, and formulas indicating the atomic linking, at least in part, are common.

Sulphuric acid is recognized as containing the ions H and SO_4 , and also as containing the groups HO and SO_2 . Hence the formulas H_2SO_4 , $(\text{HO})_2\text{SO}_2$, $\text{H}_2\text{O}_2\text{SO}_2$, and $\text{SO}_2(\text{OH})_2$. As the characteristic sulphate radical or ion SO_4 may be written O_2SO_2 it would seem to be very advantageous to write $\text{H}_2(\text{O}_2\text{SO}_2)$, for this formula shows at once the two replaceable hydrogen atoms or positive ions ("hydrions"), the SO_4 written O_2SO_2 shows that two of the oxygen atoms are linking oxygen uniting the hydrogen to the rest of the molecule, that the acidic element, S, holds all the oxygen atoms, the group SO_2 is recognized, and the two hydroxyl groups are disclosed by the fact that all replaceable hydrogen in acids is that of its hydroxyl so that the H_2O_2 will be readily understood as equivalent to $(\text{HO})_2$.

The style of structural formulas given in the 8th Revision of the Pharmacopœia of the United States are comparatively new and not generally used. The following examples will suffice to show their construction: Nitric acid is NO_2OH ; phosphoric acid $\text{PO}(\text{OH})_3$; and sulphuric acid is written $\text{SO}_2(\text{OH})_2$. Potassium nitrate is written NO_2OK ; potassium sulphate, $\text{SO}_2(\text{OK})_2$; sodium phosphate is written $\text{PO}(\text{OH})(\text{ONa})_2$; and lead nitrate $(\text{NO}_2\cdot\text{O})_2\text{Pb}$.

Students must learn to recognize all these several styles of molecular formulas in order to fully understand any of them. It is true that the group NO_2 is recognized as an atomic group in nitric acid and other nitrates, PO in phosphoric acid and other phosphates, SO_2 in sulphuric acid and other sulphates; but it has long been found advantageous to write **the basic elements or groups first in all formulas for bases and salts, and the replaceable hydrogen first in all formulas for acids.**

Convenient, systematic, significative molecular formulas are valuable and should be of uniform style.

The style to be preferred when the structure is to be indicated is shown by the following examples:

Binary compounds: H_2O ; H_2S ; KCl ; H_5N ; H_4C ; As_2O_3 ; BN ; Cu_3As_2 ; HCl ; HBr ; HF ; HI .

Bases: KOH ; $\text{Ba}(\text{OH})_2$; $\text{Fe}(\text{OH})_3$.

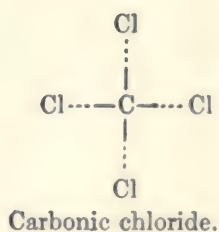
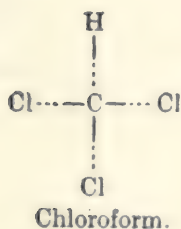
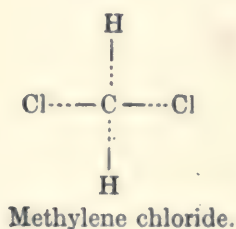
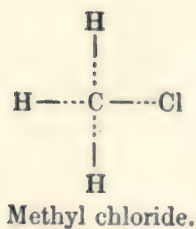
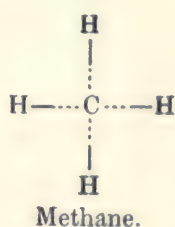
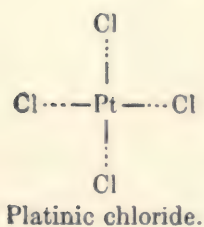
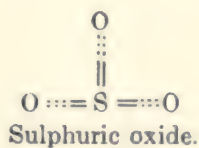
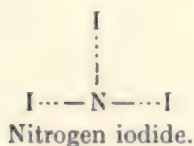
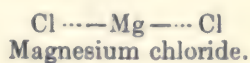
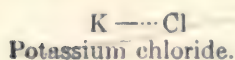
Acids: $\text{H}_3\text{O}_3\text{B}$; $\text{H}_2\text{O}_2\text{CO}$; H.ONO_2 ; H.ONO ; $\text{H}_3\text{O}_3\text{PO}$; $\text{H.OPH}_2\text{O}$; $\text{H}_2\text{O}_2\text{SO}_2$; H_2OSO ; H.OCl ; H.OClO ; H.OClO_2 ; H.OClO_3 .

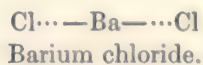
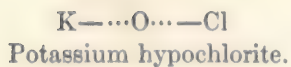
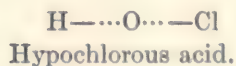
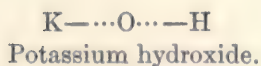
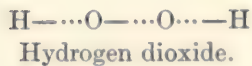
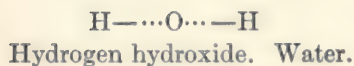
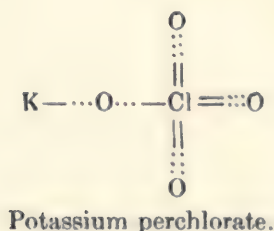
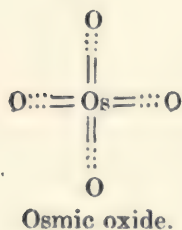
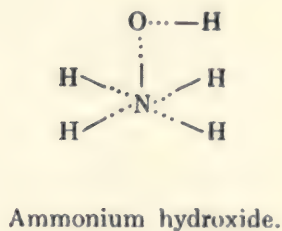
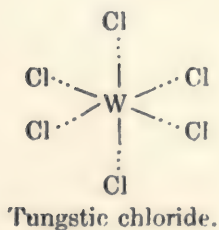
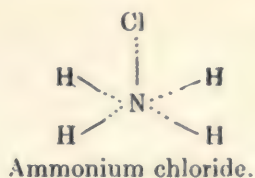
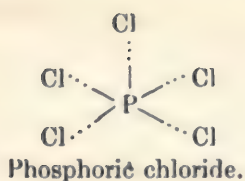
Salts: K.ONO_2 ; $\text{Ca.O}_2\text{CO}$; $\text{Na}_2\text{H.O}_3\text{PO}$; $\text{Cu.O}_2\text{SO}_2$; Na.OCl ; $\text{Fe}_2\text{(O}_2\text{SO}_2)_3$; K.OClO_2 , etc.

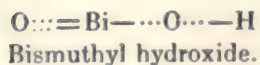
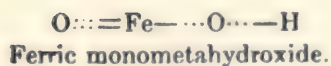
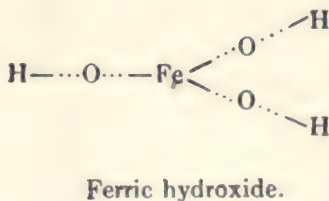
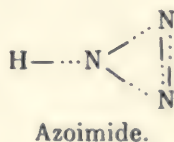
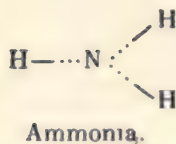
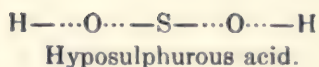
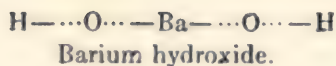
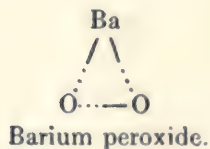
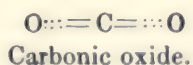
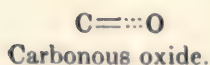
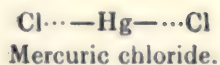
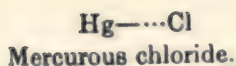
It will be seen that these formulas are significative without being too inconvenient to write. In the formulas for acids and salts the positive ions and negative ions are at once seen, and these formulas differ but little from those most commonly employed.

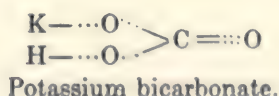
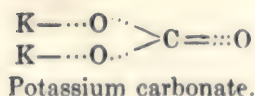
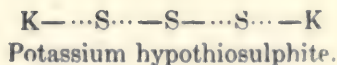
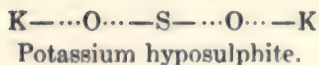
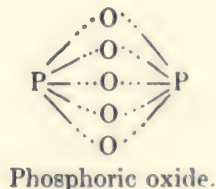
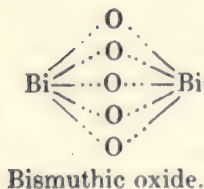
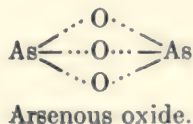
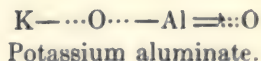
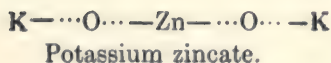
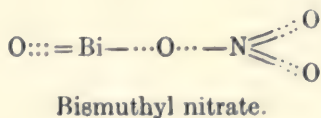
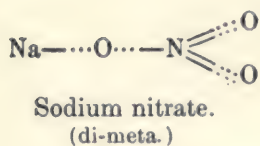
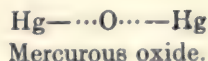
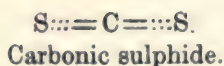
CHAPTER VI.

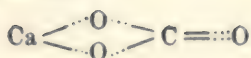
EXAMPLES OF GRAPHIC STRUCTURAL FORMULAS.



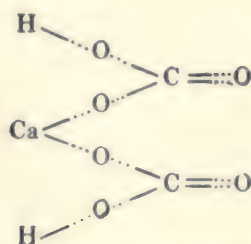




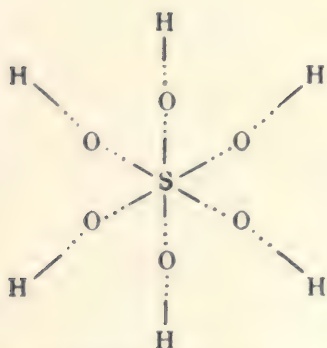




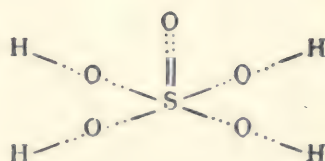
Calcium carbonate.



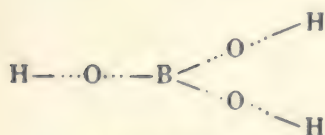
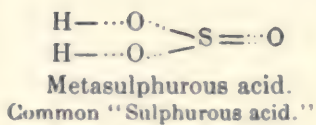
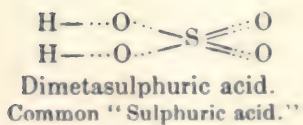
Calcium bicarbonate.



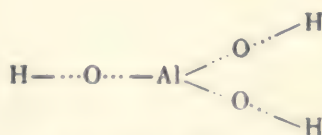
Sulphuric hydroxide.



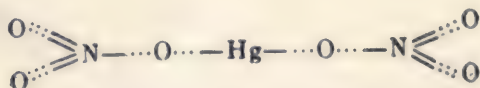
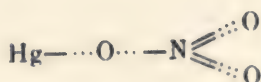
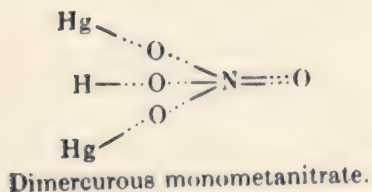
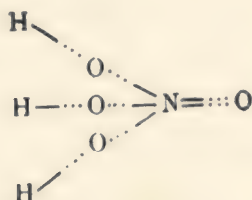
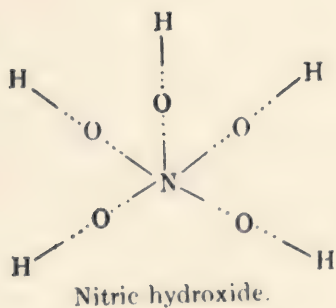
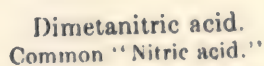
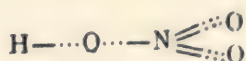
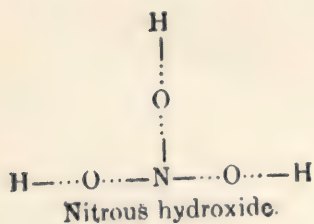
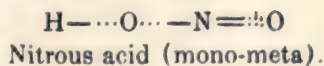
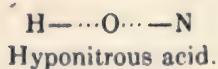
Monometasulphuric acid.

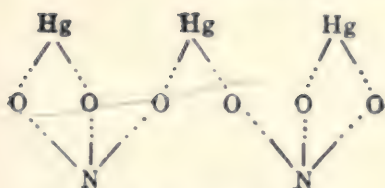


Boric acid.

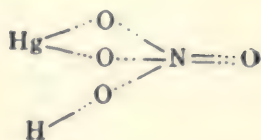


Aluminum hydroxide.

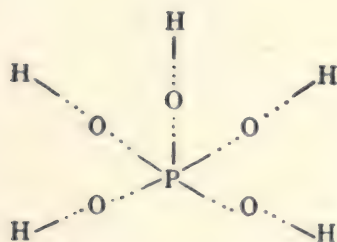




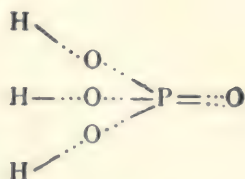
Mercuric dimeta-dinitrate.



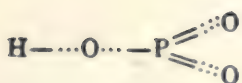
Mercuric monometanitate.



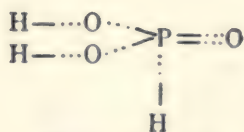
Phosphoric hydroxide.



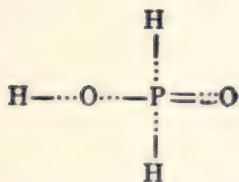
Monometaphosphoric acid.
"Orthophosphoric acid."



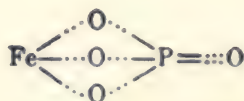
Dimetaphosphoric acid.
"Glacial phosphoric acid."



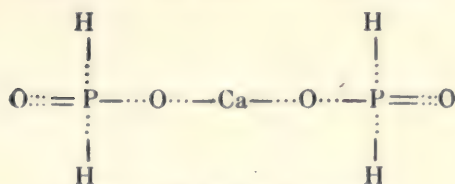
Phosphorous acid.



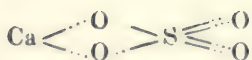
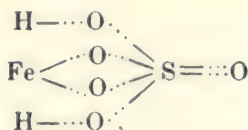
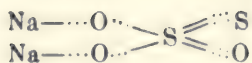
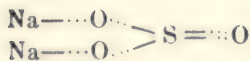
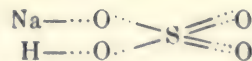
Hypophosphorous acid.



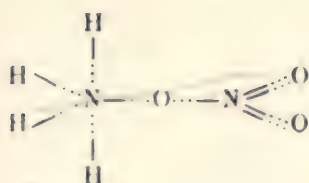
Ferric monometaphosphate.



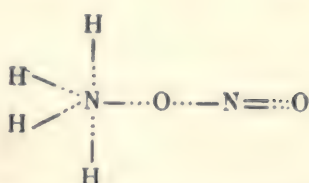
Calcium hypophosphite.

Calcium dimetasulphate.
"Calcium sulphate."Calcium dimeta-tetra-
thiosulphate.Ferrous monometasulphate.
"Dried ferrous sulphate."Sodium dimeta-monothiosulphate.
Sodium thiosulphate.Sodium dimetasulphate.
Sodium sulphate.Sodium monometasulphite.
Sodium sulphite.Primary sodium dimetasulphate
Sodium bisulphate.

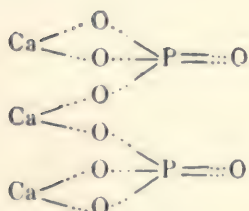
Chromic acid (di-meta)



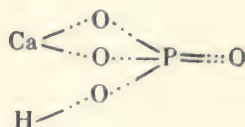
Ammonium dimetanitrate.
Ammonium nitrate.



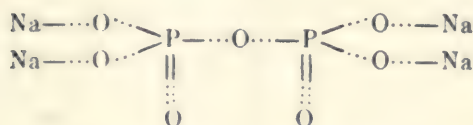
Ammonium monometanitrite.
Ammonium nitrite.



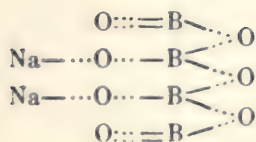
Calcium monometaphosphate.
Tri-calcium phosphate.



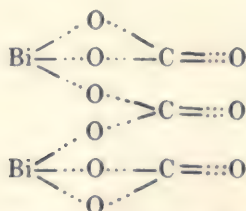
Calcium-hydrogen
monometaphosphate.



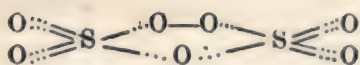
Sodium trimeta-diphosphate.
Sodium pyrophosphate.



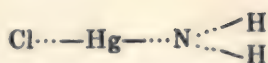
Sodium pentameta-tetraborate.
Borax.



Bismuthous monometacarbonate.
Bismuth carbonate.

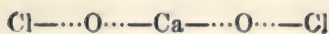


Sulphur heptoxide.

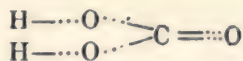


Mercuric chloramide.

"White precipitate."

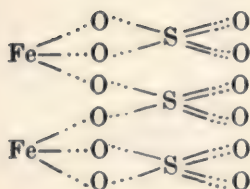


Calcium hypochlorite.



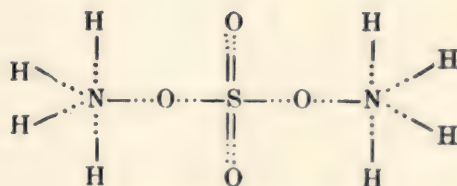
Metacarbonic acid.

Carbonic acid.



Ferric dimetasulphate.

"Tersulphate of Iron."

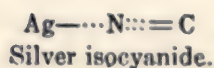
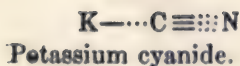


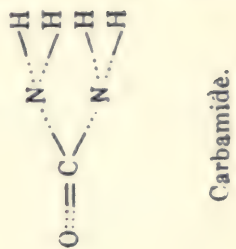
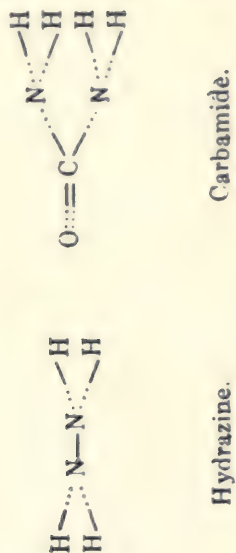
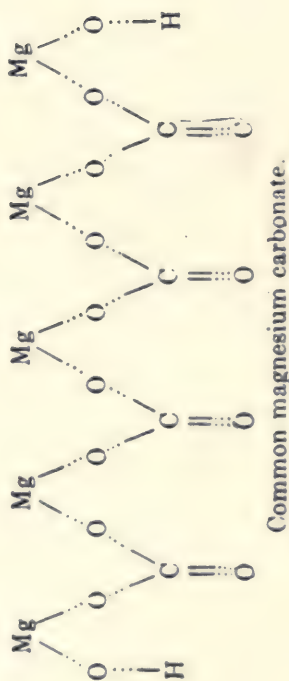
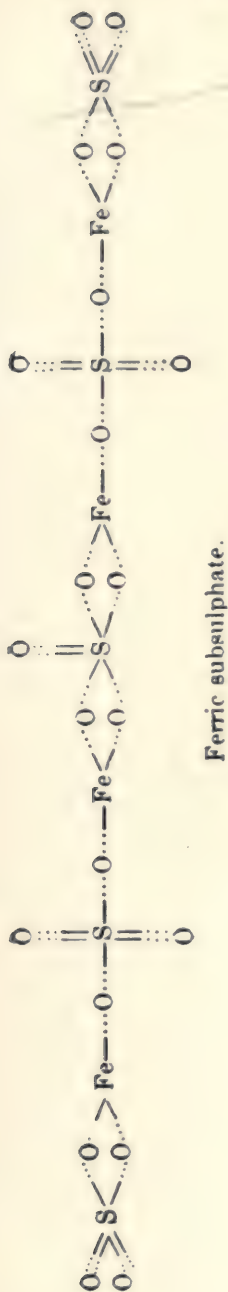
Ammonium dimetasulphate.

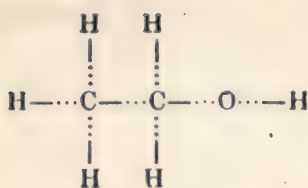
Ammonium sulphate.



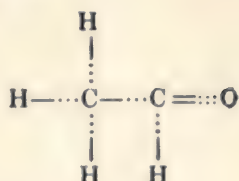
Sodium tetrathionate.



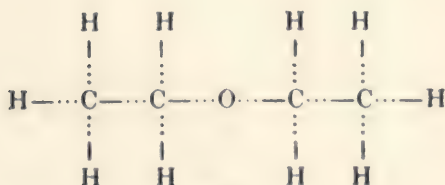




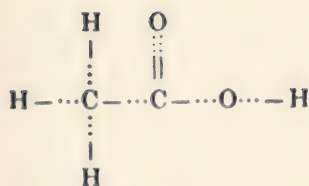
Ethyl hydroxide.
Alcohol.



Aldehyde.



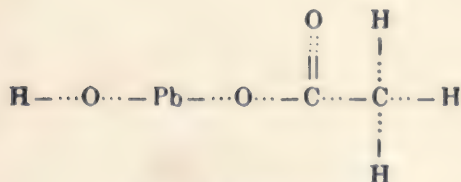
Ether.



Acetic acid.



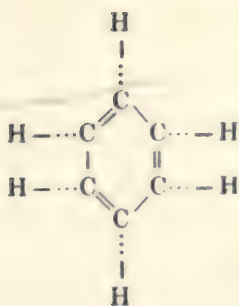
Oxalic acid.



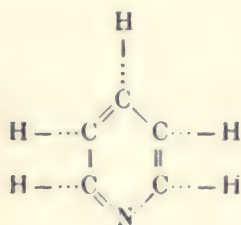
Basic lead acetate.
Subacetate of lead.



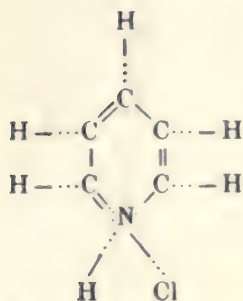
Potassium thiocyanate.



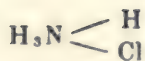
Benzene.



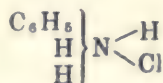
Pyridine.



Pyridine hydrochloride.



Ammonium chloride.



Aniline hydrochloride.

CHAPTER VII.

TABLE OF THE COMMON ACIDS OF MEDICINAL CHEMICALS.

Name.	Common Formula.
<i>Monobasic Acids:</i>	
Acetic	$\text{HC}_2\text{H}_3\text{O}_2$
Benzoic	$\text{HC}_7\text{H}_5\text{O}_2$
Chloric (di-meta)	HClO_3
Hypochlorous (a normal hydroxide)	HClO
Hypophosphorous	HPH_2O_2
Iodic (di-meta)	HIO_3
Lactic	$\text{HC}_3\text{H}_5\text{O}_3$
“Metaphosphoric” (di-meta)	HPO_3
Nitric (di-meta)	HNO_3
Nitrous (mono-meta)	HNO_2
Oleic	$\text{HC}_{18}\text{H}_{33}\text{O}_2$
Perchloric (tri-meta)	HClO_4
Permanganic (tri-meta)	HMnO_4
Phenolsulphonic	$\text{HC}_6\text{H}_5\text{SO}_4$
Salicylic	$\text{HC}_7\text{H}_5\text{O}_3$
Valeric	$\text{HC}_5\text{H}_9\text{O}_2$
<i>Bibasic Acids:</i>	
Arsenous	H_2AsHO_3
Carbonic (mono-meta)	H_2CO_3
Chromic (di-meta)	H_2CrO_4
Dichromic (tri-meta)	$\text{H}_2\text{Cr}_2\text{O}_7$
Oxalic	$\text{H}_2\text{C}_2\text{O}_4$
Phosphorous	H_2PHO_3
Sulphuric (di-meta)	H_2SO_4
Sulphurous (mono-meta)	H_2SO_3
Tartaric	$\text{H}_2\text{C}_4\text{H}_4\text{O}_6$
Tetraboric (penta-meta)	$\text{H}_2\text{B}_4\text{O}_7$
Tetrathiosulphuric (di-meta)	H_2SS_4
Thiosulphuric (mono-thio and di-meta)	$\text{H}_2\text{SO}_3\text{S}$

Name.	Common Formula.
<i>Tribasic Acids:</i>	
Arsenic (mono-meta)	H_3AsO_4
Boric (normal boric hydroxide)	H_3BO_3
Citric	$\text{H}_3\text{C}_6\text{H}_5\text{O}_7$
Phosphoric ("ortho-phosphoric"; mono-meta)	H_3PO_4
<i>Tetrabasic Acids:</i>	
Monometasulphuric	H_4SO_5
"Ortho-carbonic" (carbonic hydroxide of normal structure)	H_4CO_4
Pyroarsenic (tri-meta)	$\text{H}_4\text{As}_2\text{O}_7$
Pyrophosphoric (tri-meta)	$\text{H}_4\text{P}_2\text{O}_7$
Disulphuric (penta-meta)	$\text{H}_2\text{S}_2\text{O}_7$

CHAPTER VIII.

REVIEW—QUESTIONS WITH ANSWERS.

1. Write the formula for the oxide of Al and explain how it is found.

It is Al_2O_3 because each atom of Al has 3 bonds and each atom O has 2, so that in order to have the same number of bonds from each 2 atoms of Al are required and 3 of O, for $2 \times 3 = 3 \times 2$.

2. Write the formula for antimonie sulphide and account for it.

Sb_2S_5 , for S is negative toward Sb and negative S has invariably the combining value expressed by -2 , while antimonie Sb is a pentad.

3. What is the formula for hydrogen arsenide?

H_3As , because arsenic is negative in relation to H and all negative As has a combining value represented by -3 while H has the algebraic combining number $+1$.

4. Give the formula for arsenous chloride and explain it.

AsCl_3 , for arsenous As is a triad and it is positive toward Cl while the negative Cl is a monad.

5. What acids of B are possible?

As B is trivalent the only possible acids of B with only one boron atom must be H_3BO_3 , or $(\text{HO})_3\text{B}$, and the metaboric acid HBO_2 . But several boric acids with more than one atom of B exist.

6. What is "borax"?

A sodium salt with B as the acidic element. It is impossible to write its molecular formula except from memory unless a complete technical name indicating its exact composition be given. But if asked to write the formula for sodium penta-meta-tetra-borate we may at once write it without further description and without having seen it. We do so as follows:

The term "tetra" means four. A tetra-borate is a borate containing four boron atoms. B is trivalent; hence one boron atom can hold three hydroxyl groups as shown in the preceding example, and four atoms of B can hold twelve times HO. The term "penta" means five, and "penta-meta," when referring to a hydroxide, means a change of structure consisting of the loss or removal of the hydrogen and oxygen requisite to form five molecules of water. In other words a penta-meta-hydroxide is formed when ten atoms of H and five atoms of O are removed or split off. Adding together four molecules of H_3BO_3 we get $H_{12}B_4O_{12}$, and when H and O are split off to form five molecules of water the remainder will be $H_2B_4O_7$, which is penta-meta-tetra-boric acid. Its sodium salt, "borax," is, therefore, $Na_2B_4O_7$.

7. What is the formula for potassium bromate?

Bromates must be salts of which Br with a combining value of +5 constitutes the acidic element. Hence the theoretically possible potassium bromates must be derived from the hypothetical acids H_5BrO_5 , H_4BrO_4 , and $HBrO_3$. The common potassium bromate is $KBrO_3$. If we call it potassium di-meta-bromate we shall have no difficulty in writing its formula. Bromic hydroxide of normal structure would be $(HO)_5Br$, or H_5BO_5 , and the di-meta hydroxide or di-meta bromic acid must be $HBrO_3$.

8. What is the combining value of the Br in $KBrO_3$? And what is $KBrO_3$?

The only negative element in any inorganic oxygen salt is the oxygen; hence there must be six negative bonds and six positive bonds in $KBrO_3$, and as K is invariably monovalent the algebraic combining value of the Br must be +5 and a salt of which the acidic element is pentavalent Br is a bromate. $KBrO_3$ is, therefore, potassium bromate.

9. How can the S have the same combining value in $(\text{HO})_6\text{S}$, $(\text{HO})_4\text{SO}$, $(\text{HO})_2\text{SO}_2$ and SO_3 ?

Each hydrogen atom has the algebraic combining value $+1$ and each oxygen atom -2 . The sum of the combining values of 2 atoms of H and 1 atom of O must, therefore, be 0, and the algebraic combining number of the S in all these compounds must be $+6$. These compounds are all sulphuric for that reason. The algebraic combining number of any atom in combination with H and O must be the difference between the positive hydrogen bonds and the negative oxygen bonds. In $(\text{HO})_6\text{S}$ the algebraic sum of the oxygen bonds is -12 and that of the hydrogen bonds is $+6$; the difference is $+6$. In $(\text{HO})_4\text{SO}$ the oxygen bonds have a total value of -10 and the hydrogen bonds $+4$; the difference is $+6$. In $(\text{HO})_2\text{SO}_2$ the oxygen is -8 and the hydrogen $+2$, and the difference is $+6$.

10. What is sulphuric acid?

Common sulphuric acid is H_2SO_4 ; but H_6SO_6 and H_4SO_5 are also sulphuric acids, and another sulphuric acid is $\text{H}_2\text{S}_2\text{O}_7$. All that the name "sulphuric" acid indicates to us is that it is an acid of which S with a valence of 6 is the acidic element. That common sulphuric acid of 100% strength (that is, containing or consisting of 100% H_2SO_4) is H_2SO_4 can be known only from memory. But if we call it **dimeta-sulphuric acid** that name immediately leads us to the formula H_2SO_4 .

All sulphuric acids are sulphuric hydroxides. H_6SO_6 is sulphuric hydroxide of normal structure; H_4SO_5 is mono-meta-sulphuric acid; and H_2SO_4 is di-meta-sulphuric acid. $\text{H}_2\text{S}_2\text{O}_7$ is penta-meta-disulphuric acid.

11. What is the difference between H_2SO_4 , $(\text{HO})_2\text{SO}_2$, $\text{H}_2\cdot\text{O}_2\text{SO}_2$, and $\text{SO}_2(\text{OH})_2$?

None as to identity. All of these formulas represent di-meta-sulphuric acid. But the formula H_2SO_4 shows most clearly that the component ions are H and SO_4 , the formulas $(\text{HO})_2\text{SO}_2$ and $\text{SO}_2(\text{OH})_2$ show that the molecule contains two groups of HO and the group SO_2 , and the formula $\text{H}_2\cdot\text{O}_2\text{SO}_2$ shows not only that the ions are H and SO_4 but also that two of the oxygen atoms are linking oxygen or part of the hydroxyl while the other two oxygen atoms are united only to the S.

12. What is phosphoric acid?

The most common phosphoric acid is H_3PO_4 . It is generally called "orthophosphoric acid." But that name, instead of aiding us to an understanding of its structure and formula, is actually liable to mislead us, for the prefix "ortho" is used in connection with the names of acids to indicate that the composition is such that all of the oxygen is linking oxygen, or, in other words, that the only oxygen in the molecule is that of its hydroxyl. Thus $(\text{HO})_4\text{C}$ is called orthocarbonic acid, $(\text{HO})_4\text{Si}$ is called orthosilicic acid, and $(\text{HO})_3\text{B}$ is called orthoboric acid. If an ortho-acid is a hydroxide of normal structure, or, in other words, a hydroxide containing no oxygen except that of its hydroxyl and not a meta-hydroxide, then orthophosphoric acid must be $(\text{HIO})_3\text{P}$ or H_5PO_5 .

The common phosphoric acid is, however, a mono-meta-hydroxide, and if you ask me to write the molecular formula for mono-meta-phosphoric acid I shall know at once that it must be H_3PO_4 . To know that H_3PO_4 is the most common of the phosphoric acids is purely a matter of memory.

13. If H_3PO_4 is a meta-phosphoric acid, what is HPO_3 ?

It is a di-meta-phosphoric acid. It is commonly called "meta-phosphoric acid" without any qualification. That is unfortunate because ambiguous.

14. What is pyrophosphoric acid?

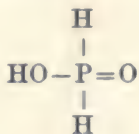
It is $\text{H}_4\text{P}_2\text{O}_7$; but the name does not tell us so. The prefix "pyro" (from **pyr**, fire) simply reminds us that pyrophosphates are produced by heating mono-meta-phosphates. But di-meta-phosphates are produced in the same way, and the knowledge that $\text{H}_4\text{P}_2\text{O}_7$ is pyrophosphoric acid, or that $\text{Na}_4\text{P}_2\text{O}_7$ is sodium pyrophosphate, is purely a matter of memory.

But if you ask me to write the molecular formula for sodium tri-meta-di-phosphate, I shall be able to write it at once: A **diphosphoric** acid must contain two atoms of P or be derived from two molecules of phosphoric hydroxide, or from $\text{H}_{10}\text{P}_2\text{O}_{10}$, and the **tri-meta**-hydroxide derived from two molecules of $(\text{HO})_3\text{P}$ can only be $\text{H}_4\text{P}_2\text{O}_7$ and its sodium salt $\text{Na}_4\text{P}_2\text{O}_7$.

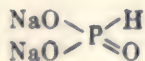
15. Since there are several phosphoric acids and the valence of the P is in all of them 5, must we conclude that all acids of phosphorus in which that element has that valence are phosphoric?

No. All phosphoric acids do contain P with a valence of 5, but there are acids of phosphorus in which the P has that valence which are not phosphoric. The safest guide to the structure of an acid from its correct and complete technical designation is not the **valence** of the acidic element but the **algebraic combining number** of that element. Sodium hypophosphite is NaPH_2O_2 , sodium phosphite is Na_2PHO_3 , and Na_2HPO_4 , NaPO_3 and $\text{Na}_4\text{P}_2\text{O}_7$ are sodium phosphates. In all of these salts the valence of the P is 5; but its algebraic combining number is +1 in all hypophosphites, +3 in all phosphites, and +5 in all phosphates.

In the hypophosphites derived from HPH_2O_2 we may at once find the algebraic combining number of the acidic element (the P) by deducting the algebraic sum (−1) of the negative oxygen bonds (−4) and the positive hydrogen bonds (+3) from 0; the answer is +1. The atom of P has 5 bonds, two of which are counted as **minus** because they hold two of the hydrogen atoms while its remaining three bonds are counted as **plus** because they are united to the oxygen atoms, and the sum of −2 and +3 is +1. There is only one hydroxyl group in HPH_2O_2 , and that is the reason why the formula is **not** written H_3PO_2 . The structure of the molecule is:



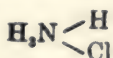
In sodium phosphite the P has a valence of 5 but its algebraic combining number is 3 because its structure is



[The structure of sodium arsenite is analogous to that of sodium phosphite. The formula for sodium meta-arsenite is NaAsO_2 , which is derived from meta-arsenous acid, HAsO_2 . In both of these arsenites it will be seen that the algebraic combining number of the As is +3, while its valence is 5 in Na_2AsHO_3 and 3 in NaAsO_2 .]

16. Write the formulas for ammonia and ammonium chloride and find the valence of the N in each and also its algebraic combining number.

H_3N is the formula for ammonia or hydrogen nitride, and



is the formula for ammonium chloride. In H_3N the nitrogen clearly has a valence of 3 and its algebraic combining number is -3 . In the ammonium chloride the N clearly has a valence of 5 but its algebraic combining number is the same as in H_3N for it holds four hydrogen atoms and one chlorine atom and the sum of -4 and $+1$ is -3 . When H_3N and HCl are brought in contact with each other the N changes its valence from 3 to 5; its two newly acquired bonds do not change its algebraic combining number because one of these bonds is negative (uniting it to the positive hydrogen from the HCl) while the other is positive (uniting the N to the Cl), and the sum of -1 and $+1$ is 0. The H and the Cl of the HCl are separated when HCl and H_3N form H_4NCl .

The algebraic combining number of the N in all ammonium compounds is the same as in ammonia.

Whenever ammonia forms a salt by reaction with a hydroxyl acid the N of the ammonia separates the hydron of the acid from the negative ion or acid radical. In doing this it must be assumed to acquire two additional bonds, one positive to hold the negative ion and one negative to hold the positive ion or hydron of the acid, the product being an ammonium salt.

17. What is the formula for potassium nitrite?

Common potassium nitrite is represented by the formula KNO_2 . But it would be impossible to know that except by the process of memorization, which is usually called "cramming." If you ask me, instead, to write the formula for potassium metanitrite I would know that it must be KNO_2 ; for nitrites are the salts of nitrous acid, nitrous acid is nitrous hydroxide, which must be $(\text{HO})\text{N}$ or an acid containing trivalent nitrogen as its acidic element, and nitrous meta-hydroxide must be HNO_2 . That nitrous compounds contain nitrogen with a combining value of $+3$ [ammonium compounds contain N with a combining value of -3] is evident from the position of N

in the periodic system. But, unfortunately, some nitrogen oxides are misnamed so that confusion is created, for N_2O , which can not consistently be named anything but hyponitrous oxide, is commonly called nitrous oxide, whereas the only oxide which can consistently be named nitrous oxide and which forms nitrous acid with water is N_2O_3 .

18. Write the formulas for nitric oxide and nitric acid.

The normal valences of N are 1, 3 and 5, as may be known from its position in the periodic system of classification of the elements. Hence the N of nitric compounds has a valence of 5, that of nitrous compounds a valence of 3, and that of hyponitrous compounds a valence of 1. Nitric oxide, then, must be N_2O_5 and the corresponding acids must be H_5NO_5 , H_3NO_4 and HNO_3 . But, unfortunately, N_2O_5 is not called nitric oxide, although HNO_3 is called nitric acid, and NO (nitrosyl) is commonly called nitric oxide although the N in that compound has a valence of 2 instead of 5.

Common nitric acid is nitric dimeta-hydroxide, or HNO_2 .

19. What is Na_2S_5 ?

As Na is invariably a positive element and a monad the sum of the combining numbers of the two atoms of Na must be +2. Hence the sum of the combining numbers of the five sulphur atoms must be -2. It is evident, then, that the sulphur atoms can not all have the same combining value for it would be absurd to ascribe to them such a valence as $\frac{2}{5}$ each. To make the sum of the algebraic combining numbers of the five sulphur atoms -2 we are obliged to assume that one sulphur atom has the value represented by +6 and the other four the value of -2 each. The total sum would then be -2 for the sum of +6 and -8 is -2. Therefore, Na_2S_5 must be analogous to Na_2SO_4 which is sodium dimetasulphate. In other words, Na_2S_5 is Na_2SS_4 or sodium dimetatetrathiosulphate.

20. What is the difference between HgH_2NCl and H_2NHgCl ?

The first formula is based on the assumption that the N is a pentad and that the Cl is united directly to the N. The name of the compound should then be mercur-ammonium chloride. It was once so named.

The second formula is based on the assumption that the N is a triad and that the Hg holds the Cl as well as the H_2N . This compound, then, is called mercuric chloramide, which is doubtless the true designation of the substance.

21. What is the difference between HCN and HNC?

The first is hydrogen cyanide, commonly called "hydrocyanic acid." The formula is based upon the assumption that the C is a tetrad and its algebraic combining number +2 for carbon is a negative element in relation to H but a positive element in relation to N and the sum of -1 and $+3$ is $+2$. [Negative N always has the algebraic combining number -3 .]

The second formula represents hydrogen isocyanide. The N in it has the combining value -3 and a valence of 3, and the C has a valence of 2 and the algebraic combining value $+2$. To assume that the N in HNC has a valence of 5 and the C a valence of 4 would be a violent assumption, because an element which, like N, has a highest algebraic combining value of $+5$ (as in nitric acid) can not have an algebraic combining number lower than -3 .

22. How many hydrogen atoms are contained in the molecule of any acid containing four oxygen atoms and the acidic element of which is a non-metallic element?

As many hydrogen atoms as one atom of the acidic element can hold in combination with itself. Thus dimetasulphuric acid, H_2SO_4 , contains two hydrogen atoms because hydrogen sulphide is H_2S . The perchloric acid $HClO_4$ contains one atom of H, because hydrogen chloride is HCl.

23. Give the comparative numbers of the oxygen atoms and hydrogen atoms in the molecules of meta-acids.

In mono-meta-acids the number of oxygen atoms exceeds the number of hydrogen atoms by 1; in di-meta-acids by 2; in tri-meta-acids by 3; in tetra-meta-acids by 4; in penta-meta-acids by 5; etc.

24. How do you recognize a meta-acid?

By the fact that the number of oxygen atoms in its molecule is less than that expressing the valence of the acidic element.

A mono-meta-acid contains one oxygen atom less than the number representing the valence units of the acidic element;

a di-meta-acid 2 less than that number; a tri-meta-acid 3 less; a tetra-meta-acid 4 less; a penta-meta-acid 5 less.

25. Give the numbers of oxygen atoms and hydrogen atoms in penta-meta-tetraboric acid.

The valence-units of 4 boron atoms are 12; the oxygen atoms must, therefore, be 7, or 5 less than 12, and the hydrogen atoms must be 5 less than 7, or 2.

26. What is valence?

It is a number representing the charges of electricity carried by any individual atom, whether of positive or negative electricity, or both.

A monovalent atom carries one charge; a divalent atom, two; a trivalent atom, three; a tetravalent atom, four; a pentavalent atom, five; a hexavalent atom, six; a heptavalent atom, seven; and an octovalent atom carries eight charges of electricity.

24. What is meant by the term bond?

It is used for convenience to express the units of valence of any atom in actual combination. Its utility consists in that bonds may be represented by lines by means of which the assumed mutual connections between the component atoms of a molecule may be traced or pictured, thus showing the internal structure or interatomic linkage.

Bonds representing charges of positive electricity are called positive bonds; those representing charges of negative electricity are called negative bonds.

27. How can positive elements or atoms and negative atoms or elements be identified?

By their relative positions in the periodic system.

Metals and hydrogen are positive elements in relation to all other elements; oxygen and fluorine are negative elements in relation to all other elements; and the elements

Cl, Br, I, S, Se, Te, N, P, As, Sb, C and Si are positive or negative according to their relative positions in the line in which they are here named by their symbols. Any one of these non-metallic elements is negative when combined with any element to its right, but positive when in combination with any element to the left.

Any two atoms directly combined with each other must be one of them endowed with positive electricity and the other with negative electricity. They must be held to each other by an even number of bonds one-half of which are positive and belong to one of the atoms while the other half are negative bonds and belong to the other atom.

28. Are all the bonds of any atom of the same polarity?

All the bonds of any given atom in combination are generally of one polarity, either positive or negative, because in most compounds the positive atoms are combined exclusively with negative atoms or the negative atoms exclusively with positive atoms; but when any atom is united by one or more of its bonds to a relatively positive element and by one or more other bonds to a relatively negative element, then its polarity is partly negative and partly positive. Thus a nitrogen atom combined with both hydrogen and oxygen is negative to the former but positive to the latter, and is held to the hydrogen by negative bonds but to the oxygen by positive bonds.

29. By what method can the respective polarities of the atoms contained in the most common inorganic compounds be seen at a glance?

The most common component elements of inorganic compounds are the metals, oxygen, hydrogen, sulphur and the halogens.

As the metals and hydrogen are positive elements in relation to all others, it follows that the other elements are negative when in immediate combination with metals or with hydrogen. As oxygen is invariably of negative polarity when in combination with any other element, it follows that atoms immediately combined with oxygen are always positive. Sulphur is negative toward all other elements except oxygen and the halogens. The halogens are negative toward all other elements except oxygen.

30. What is the valence of a free atom, and the valence of a molecule?

As valence means the number of bonds of any atom when it is in actual combination, it follows that an uncombined atom has no valence or a valence of 0.

A molecule must also have a valence of 0 because all its component atoms are in actual combination with each other by means of all their bonds, which cancel each other, so that the molecule as a whole has no uncanceled bond.

31. Is it practicable to determine the valence of each atom in combination in any molecule?

As the valences of certain elements are invariably the same in all their compounds it follows that the valences of other elements are disclosed by their connections with atoms of constant valence. All atoms of exclusively negative polarity have constant valences, and the valences of other atoms are seen from the valences of the negative elements. Moreover, hydrogen in combination with any other element has invariably a valence of 1 and oxygen a valence of 2.

Sulphur in all its compounds with other elements except oxygen and the halogens has a constant valence of 2; and the halogens in combination with all other elements except oxygen have an invariable valence of 1.

32. What is the difference between valence and algebraic combining value?

The valence of an atom is the arithmetical sum of its bonds when in actual combination, without reference to polarity; the algebraic combining value of an atom is the algebraic sum of its positive and negative bonds, counting the positive bonds (or charges of positive electricity) as each having the value of +1 and the negative bonds (or charges of negative electricity) as each having the value of -1.

An atom of Sr when in combination has two bonds; its valence is, therefore, 2. Both of those bonds are positive bonds; its algebraic combining value is, therefore, +2. In the molecule SrCl_2 the valence of each atom of Cl is 1; but the algebraic combining number of each chlorine atom is -1.

In the molecule OSbCl the valence of the oxygen atom is 2, that of the antimony atom is 3 and that of the chlorine 1; the algebraic combining values are -2, +3 and -1.

In the molecule H_3CI the hydrogen atoms have each a valence of 1, the C a valence of 4 and the iodine a valence of 1; the algebraic combining number of the hydrogen atom is +1, that of the C is -2, and that of the I is -1.

33. What is the valence of any atom immediately combined with another atom of the same element, and what is its algebraic combining number?

All that we know is that the bonds by which any two atoms are held in combination with each other must be an equal number belonging to each and that the algebraic sum of those bonds must be 0.

Thus in H_2S the two sulphur atoms are united to each other by an even number of bonds the algebraic sum of which must be 0, while the sulphur bonds holding the hydrogen atoms must each have the value of -1 .

34. Can the algebraic combining numbers of the component atoms of complex molecules containing chains of atoms of the same element be determined in any way?

They are at once disclosed by graphic structural formulas. But the algebraic sums of all atoms of each element may be seen even from the empiric-molecular formulas of, for example, all compounds of carbon, hydrogen and oxygen.

In the molecular formula $\text{C}_6\text{H}_{10}\text{O}_5$ it is evident that the algebraic sum of the hydrogen bonds must be $+10$, and that of the oxygen bonds -10 ; the algebraic sum of the hydrogen bonds and oxygen bonds together is, therefore, 0; and as the total algebraic sum of all the bonds of all the atoms of the whole molecule must also be 0, it follows that the algebraic sum of the carbon bonds is 0, too, which means that one-half of the carbon bonds are positive and the other half negative.

CHAPTER IX.

TABLE OF ALGEBRAIC COMBINING NUMBERS OF THE COMMON ELEMENTS IN THEIR COMMON COMPOUNDS.

Aluminum.—Invariably +3.

Antimony.—In antimonous compounds +3; in antimonic compounds +5; antimony of negative polarity —3.

Arsenic.—In arsenous compounds +3; in arsenic compounds +5; negative As —3.

Barium.—Invariably +2. [Barium peroxide is assumed to have the structure



Bismuth.—In bismuthous compounds +3; in bismuthic compounds +5.

Boron.—Its valence is always 3; in its hydrogen compound the algebraic combining number must be —3, and in all its other known compounds +3.

Bromine.—In hypobromites its combining value is +1, and in bromates +5. Bromous and perbromic compounds are not known. It forms a chloride which is hypobromous, BrCl. In all bromides the algebraic combining number of Br is —1. It is a negative element in all its compounds except when directly combined with Cl, F or O.

Cadmium.—Invariably +2.

Calcium.—Invariably +2.

Carbon.—In the carbonates and other carbonic compounds the combining value of C is +4. In CO it is +2.

In nearly all organic chemical compounds the C is assumed to have a **valence** of 4. But in the isocyanides its valence is assumed to be 2.

The algebraic combining number of carbon may be +4, +2, 0, —2, or —4 according to its connections. This may be seen from the molecules CS₂, CO and AgNC, HCCl₃, H₂CCl₂, H₃CCl and H₄C.

Compounds of C, H and O must all contain an even number of atoms of H.

The total of the algebraic combining numbers of the carbon atoms in any compound of C, H and O is found by deducting the algebraic sum of the oxygen bonds and the hydrogen bonds from 0.

Cerium.—In ceric compounds +4; in cerous compounds +3.

Chlorine.—In perchloric compounds +7; in chloric compounds +5; in chlorous compounds +3; in hypochlorous compounds +1; in chlorine dioxide, ClO_2 , it is +4.

Chlorine is of negative polarity in all its known compounds except when in immediate combination with oxygen. It is hypothetically positive toward fluorine but no fluoride of Cl is known.

Negative Cl has a combining value of -1 .

Chromium.—Acidic chromium has a combining value of +6. This combining number, then, is shown in acidic chromic oxide, CrO_3 , and in all chromates.

The combining value of Cr in chromous compounds is +2, and in chromic compounds in which the Cr is not acidic its combining number is +3, as in the basic chromic oxide, Cr_2O_3 , and in chrome alum.

Cobalt.—In cobaltic compounds +3; in cobaltous compounds +2.

Copper.—In cupric compounds +2; in cuprous compounds +1.

Fluorine.—Invariably -1 .

Gold.—In auric compounds +3; in aurous compounds +1.

Hydrogen.—In all compounds +1 (except in chemical combination with true metals, when its value is -1).

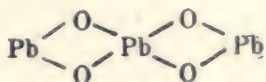
Iodine.—In periodic compounds +7; in iodic compounds +5; in iodous compounds +3 (as in ICl_3); in hypo-iodous compounds (as in IBr) +1. In all other iodine compounds the I has a combining value of -1 .

Iron.—The compounds in which the iron performs the acidic function are the ferrates and the ferrites. In ferrates the Fe has a combining value of +6; in ferrites +3.

Other iron compounds are called ferric when the Fe has a combining value of +3; ferrous when its combining value is +2.

Lead.—The normal combining values of lead might be expected to be 4 and 2 from its position in the periodic system. (It is in the same group with carbon.) These values are exhibited in the “peroxide,” PbO_2 , and in the oxide, PbO . But the most common lead compounds contain Pb with a combining value of +2.

[The lead compounds in which that metal is a dyad are unfortunately called plumbic, and those in which the Pb is a tetrad are called per-plumbic. Consistency would require that the former compounds be called plumbous, and the latter plumbic.] The compound Pb_3O_4 is either a molecular combination of 2PbO with PbO_2 , or it may be



Lithium.—Invariably +1.

Magnesium.—Invariably +2.

Manganese.—The valence of Mn is very irregular. Acidic manganese has a combining value of +7 in the permanganic compounds; +6 in manganates; and +4 in manganites.

The compounds in which the Mn is not acidic are called manganic when the metal has a combining value of +3, and manganous when it has a value of +2.

The combining value of the Mn in the dioxide is +4.

Mercury.—In mercuric compounds +2; in mercurous compounds +1.

Molybdenum.—Its combining values are very irregular, being 2, 3, 4, 5 and 6, as shown by the chlorides MoCl_2 , MoCl_3 , MoCl_4 , and MoCl_5 and by the oxides MoO , Mo_2O_3 , MoO_2 and MoO_3 . The most important compounds are the molybdates in which the Mo has the combining value of +6. A large number of meta-molybdates (“polymolybdates”) are known.

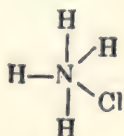
Nickel.—In nickelic compounds +3; in nickelous compounds +2.

Nitrogen.—Apparently irregular in its combining values. The normal combining values are +5 in nitric compounds, as in N_2O_5 and HNO_3 ; +3 in nitrous compounds, as in N_2O_3 and

HNO_2 ; +1 in hyponitrous compounds, as in N_2O and the hyponitrites; and -3 in ammonia and the ammonium compounds.

The valence of the N in the ammonium compounds is always 5; but the algebraic combining number of the N in those compounds is always the same as in ammonia, namely -3. The combining value of the N in albumin and in all alkaloids is also -3.

That the N in ammonium chloride has a valence of 5 but an algebraic combining number of -3 is readily seen from the structural formula—



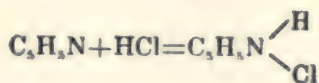
which shows that the nitrogen atom has 4 bonds holding hydrogen atoms and 1 bond holding the chlorine (the sum of -4 and +1 is -3).

The nomenclature of some of the nitrogen compounds is inconsistent and confusing. Thus the hyponitrous oxide, N_2O , is commonly called "nitrous oxide;" the nitrous oxide, N_2O_3 , is called nitrogen trioxide; nitrosyl, NO , is commonly called "nitric oxide;" the nitric oxide, N_2O_5 , is called nitrogen pentoxide; nitryl, NO_2 , is commonly called nitrogen tetroxide (from its double molecule N_2O_4).

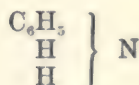
In compounds containing two or more nitrogen atoms directly united to each other the combining value of each nitrogen atom is not apparent; but the total algebraic sum of the combining units of the nitrogen atoms in such compounds is seen from the atoms of the other elements with which the N is combined. Thus in HN_3 we know that the total of the combining units of the nitrogen atoms must be -1. The hydrogen must be held by 1 nitrogen bond; the algebraic sum of the nitrogen bonds holding the several nitrogen atoms to each other must be 0. Similar conditions are to be observed in $\text{H}_2\text{N}-\text{NH}_2$, etc.

The algebraic combining value of the N in H_2NCl must be -1; in HNCl_2 it is +1; and in NCl_3 it is +3.

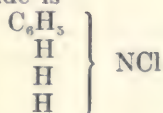
In pyridine, C_5H_5N , the nitrogen has a valence of 3 and its algebraic combining number is -3 ; but in pyridine hydrochloride the N has a valence of 5 while it retains its algebraic combining number of -3 :



Aniline is



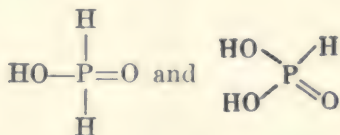
Aniline hydrochloride is



Oxygen.—Invariably -2 when the oxygen is combined with another element. But two or more oxygen atoms are sometimes in direct combination with each other; as in $HO.OH$, O_3 , BaO_2 , and S_2O_7 ; then the bonds by which the oxygen atoms are held to each other have a total algebraic value of 0.

Phosphorus.—In phosphoric compounds $+5$; in phosphorous compounds $+3$; in hypophosphorous compounds $+1$; in phosphine and other phosphides -3 .

But the valence of P in both hypophosphorous acid and phosphorous acid is 5 for the structure is



The nomenclature of the salts of which phosphorus is the acidic element is based upon the proportion of oxygen (in conformity to the general custom); but while nomenclature is not in all cases in harmony with valence it always agrees with the algebraic combining numbers when consistent.

Platinum.—In platonic compounds $+4$; in platinous compounds $+2$.

Potassium.—Invariably $+1$.

Silicon.—In silicic compounds $+4$; in silicides -4 .

Silver.—Invariably $+1$.

Sodium.—Invariably $+1$.

Strontium.—Invariably $+2$.

Sulphur.—In sulphuric compounds $+6$; in sulphurous compounds $+4$; in hyposulphurous compounds $+2$; in sulphides -2 . The sulphur of thio-salts (performing the same function in those salts as the oxygen performs in oxygen salts) has a combining value like that of oxygen (-2).

Tin.—In stannic compounds $+4$; in stannous compounds $+2$.

Zinc.—Invariably $+2$.

CHAPTER X.

EXERCISES IN WRITING MOLECULAR FORMULAS (COMMON AND GRAPHIC STRUCTURAL FORMULAS).

Binary Compounds.

Write the formulas for :

- | | |
|------------------------|----------------------------|
| 1. Lithium chloride. | 28. Carbonous oxide. |
| 2. Silver bromide. | 29. Carbonic chloride. |
| 3. Zinc oxide. | 30. Hydrogen carbide. |
| 4. Barium sulphide. | 31. Stannous chloride. |
| 5. Boron nitride. | 32. Stannic chloride. |
| 6. Cuprous iodide. | 33. Lead oxide. |
| 7. Cupric chloride. | 34. Lead sulphide. |
| 8. Cupric oxide. | 35. Lead chloride. |
| 9. Cuprous oxide. | 36. Hydrogen nitride. |
| 10. Silver oxide. | 37. Hyponitrous oxide. |
| 11. Cadmium sulphide. | 38. Nitrous oxide. |
| 12. Ferrous bromide. | 39. Nitric oxide. |
| 13. Calcium iodide. | 40. Nitrous iodide. |
| 14. Aluminum oxide. | 41. Hypophosphorous oxide. |
| 15. Aluminum chloride. | 42. Phosphoric oxide. |
| 16. Ferric chloride. | 43. Phosphorous chloride. |
| 17. Ferrous sulphide. | 44. Phosphoric chloride. |
| 18. Ferric sulphide. | 45. Arsenous oxide. |
| 19. Cupric arsenide. | 46. Arsenic oxide. |
| 20. Zinc phosphide. | 47. Arsenous iodide. |
| 21. Auric chloride. | 48. Antimonous sulphide. |
| 22. Zinc bromide. | 49. Antimonic sulphide. |
| 23. Mercurous iodide. | 50. Antimonous chloride. |
| 24. Mercuric bromide. | 51. Bismuthous oxide. |
| 25. Mercurous oxide. | 52. Bismuthic oxide. |
| 26. Mercuric oxide. | 53. Sulphurous oxide. |
| 27. Carbonic oxide. | 54. Sulphuric oxide. |

- | | |
|---------------------------|-------------------------|
| 55. Chromic anhydride. | 66. Ammonia. |
| 56. Basic chromic oxide. | 67. Water. |
| 57. Chromous chloride. | 68. Hydrogen chloride. |
| 58. Manganous chloride. | 69. Hydrogen bromide. |
| 59. Stibine. | 70. Hydrogen oxide. |
| 60. Barium peroxide. | 71. Hydrogen sulphide. |
| 61. Hypobromous chloride. | 72. Nitrosyl. |
| 62. Arsine. | 73. Manganese dioxide. |
| 63. Iodous chloride. | 74. Platinic chloride. |
| 64. Hypo-iodous bromide. | 75. Cobaltous chloride. |
| 65. Lead peroxide. | 76. Cobaltic chloride. |

Hydroxides.

Write the formulas for the hydroxides of:

- | | |
|---------------|-----------------|
| 77. Hydrogen. | 83. Ferrous Fe. |
| 78. K. | 84. Ferrie Fe. |
| 79. Na. | 85. B. |
| 80. Mg. | 86. Al. |
| 81. Ca. | 87. Zn. |
| 82. Ba. | |

Write the formulas of:

88. Boric acid.
89. Metaboric acid.
90. Cupric hydroxide.
91. Zinc hydroxide.
92. Carbonic metahydroxide.
93. Metacarbonic acid.
94. Orthocarbonic acid.
95. Orthosilicic acid.
96. Monometasilicic acid.
97. Hyponitrous acid.
98. Monometanitric acid.
99. Dimetanitric acid.
100. Nitrous hydroxide.
101. Metanitrous acid.
102. Hypophosphorous hydroxide.

103. Hypophosphorous acid.
104. Phosphoric hydroxide.
105. Phosphoric monometahydroxide.
106. Phosphoric dimetahydroxide.
107. Orthophosphoric acid.
108. Trimeta-diphosphoric acid.
109. Pyrophosphoric acid.
110. Phosphorous hydroxide.
111. Metaphosphorous acid.
112. Arsenous acid.
113. Metarsenous acid.
114. Pentameta-tetraboric acid.
115. Arsenic hydroxide.
116. Arsenic monometa-hydroxide.
117. Dimeta-arsenic hydroxide.
118. Antimonic monometa-hydroxide.
119. Metantimonous acid.
120. Bismuthous hydroxide.
121. Sulphuric hydroxide.
122. Sulphuric monometa-hydroxide.
123. Monometasulphuric acid.
124. Dimetasulphuric acid.
125. Common sulphuric acid.
126. Pentameta-disulphuric acid.
127. Sulphurous hydroxide.
128. Metasulphurous acid.
129. Ordinary sulphurous acid.
130. Hyposulphurous acid.
131. Perchloric trimeta-hydroxide.
132. Dimetachloric acid.
133. Ordinary chloric acid.

Salts.

Write the molecular formulas for:

134. Lithium chlorate (dimeta).
135. Potassium chlorate (dimeta).
136. Sodium hypochlorite.
137. Calcium hypochlorite.

138. Sodium hypophosphite.
139. Calcium hypophosphite.
140. Manganous hypophosphite.
141. Ferrous hypophosphite.
142. Ferric hypophosphite.
143. Potassium iodate (dimeta).
144. Calcium dimeta-phosphate.
145. Sodium nitrate (dimeta).
146. Mercurous nitrate (dimeta).
147. Mercuric nitrate (dimeta).
148. Zinc nitrate (dimeta).
149. Aluminum nitrate (dimeta).
150. Bismuthous nitrate (dimeta).
151. Ferrous nitrate (dimeta).
152. Ferric nitrate (dimeta).
153. Silver nitrate (dimeta).
154. Sodium metanitrite.
155. Sodium hyponitrite.
156. Potassium perchlorate (trimeta).
157. Sodium permanganate (trimeta).
158. Di-sodium arsenite.
159. Di-potassium arsenite.
160. Potassium metarsenite.
161. Magnesium orthocarbonate.
162. Di-sodium-dihydrogen-orthocarbonate.
163. Sodium metacarbonate.
164. Sodium hydrogen carbonate.
165. Sodium "bicarbonate."
166. Calcium carbonate (meta).
167. Barium carbonate.
168. Potassium "acid carbonate."
169. Sodium dimeta-chromate.
170. Sodium trimeta-dichromate.
171. Potassium dimeta-sulphate.
172. Potassium hydrogen dimetasulphate.
173. Sodium sulphate (dimeta).
174. Sodium "bisulphate" (dimeta).
175. Calcium sulphate (dimeta).
176. Calcium bisulphate (dimeta).

177. Ferrous monometasulphate.
178. Ferrous dimetasulphate.
179. Zinc sulphate (monometa).
180. Ferric sulphate (dimeta).
181. Sodium sulphite.
182. Calcium sulphite.
183. Borax (sodium penta-meta-tetraborate).
184. Calcium tetrathiosulphate (dimeta).
185. Sodium monothiosulphate (dimeta).
186. Sodium phosphate (di-sodium monometa-phosphate).
187. Tri-calcium phosphate (monometa).
188. Mono-calcium monometaphosphate.
189. Ferric "orthophosphate."
190. Ferric monometaphosphate.
191. Ferric pyrophosphate (trimeta-diphosphate).
192. Sodium arsenate (di-sodium-monometa-arsenate).
193. Potassium manganate.
194. Potassium chromate.
195. Sodium ferrate.
196. Cerous oxalate.

Miscellaneous.

Write the molecular formulas for:

197. Hydrogen fluoride.
198. Hydrogen silicide.
199. Hydrogen sulphide.
200. Hydrogen hydroxide.
201. Hydrogen oxide.
202. Hydrogen dioxide.
203. Hydrogen disulphide.
204. Hypochlorous acid.
205. Ammonium chloride.
206. Bismuthyl nitrate.
207. Bismuthyl chloride.
208. Sulphur iodide.
209. Mercuric sulphide.
210. Potassium hypo-thiosulphite.
211. Sulphurous oxide.

212. Sulphuric oxide.
213. Ammonium sulphate.
214. Ferric alum.
215. Potassium alum.
216. Ammonium alum.
217. Sodium-chromium alum.
218. Mercuric sulphate.
219. Mercurous sulphate.
220. Mercuric chloramide.
221. Ammonium nitrate.
222. Sodium-ammonium-hydrogen monometaphosphate.
223. Ferrous monometaphosphate.
224. Boron monometaphosphate.
225. Calcium pyrophosphate.
226. Ordinary ammonium carbonate.
227. Ordinary magnesium carbonate.
228. Ordinary lead carbonate.
229. Ordinary zinc carbonate.
230. Hydrogen cyanide.
231. Potassium cyanide.
232. Mercuric cyanide.
233. Silver isocyanide.
234. Antimonyl-potassium tartrate
235. Sodium thioantimonite.
236. Sodium thioantimonate.
237. Tungstic chloride.
238. Bismuth citrate.
239. Cupric acetate.
240. Lead nitrate.
241. Lead acetate.
242. Chromic chloride.
243. Chromic acid (dimeta).
244. Ferrous hydroxide.
245. Ferric hydroxide.
246. Ferric monometahydroxide.
247. Diferric monometahydroxide.
248. Ferric acetate.
249. Nickelous oxide.
250. Nickelic chloride.

251. Nickelie arsenide.
252. Cobaltic sulphide.
253. Sodium zincate.
254. Magnesium sulphite.
255. Sodium bisulphite.
256. Sodium hyposulphite.
257. Potassium-sodium tartrate.
258. Sodium-dihydrogen citrate.
259. Di-sodium-hydrogen citrate.
260. Tri-sodium citrate.
261. Tri-hydrogen citrate.
262. Citric acid.
263. Acetic acid.
264. Tartaric acid.
265. Valeric acid.
266. Benzoic acid.
267. Lactic acid.
268. Oleic acid.
269. Salicylic acid.
270. Phenolsulphonic acid.
271. Potassium dichromate.
272. Potassium bichromate (potassium-hydrogen dimeta-chromate).
273. Ammonium bitartrate.
274. Ammonium hydroxide.
275. Bismuth citrate.
276. Ferrous lactate.
277. Bismuth salicylate.
278. Zinc phenolsulphonate

RECOGNITION OF MOLECULAR FORMULAS.

Give the correct technical names of:

- | | |
|-------------------|-------------------|
| 279. $B(OH)_3$. | 284. $(HO)_4C$. |
| 280. H_3BO_3 . | 285. H_4CO_4 . |
| 281. $(HO)_3B$. | 286. $(HO)_2CO$. |
| 282. HBO_2 . | 287. H_2CO_3 . |
| 283. $HOB(O)_2$. | 288. $(HO)_6S$. |

- | | |
|---|---|
| 289. $(\text{HO})_4\text{S}$. | 326. $(\text{HO})_2\text{P}_4\text{O}_5$. |
| 290. $(\text{HO})_4\text{SO}$. | 327. K_2HAsO_3 . |
| 291. H_4SO_5 . | 328. K_2AsHO_3 . |
| 292. H_2SO_4 . | 329. $(\text{KO})_2\text{AsHO}$. |
| 293. $(\text{HO})_2\text{SO}_2$. | 330. K_2HAsO_4 . |
| 294. $\text{H}_2\text{O}_2\text{SO}_2$. | 331. HCl . |
| 295. $\text{H}_2(\text{O}_2\text{SO}_2)$. | 332. HClO . |
| 296. $\text{SO}_2(\text{OH})_2$. | 333. HClO_2 . |
| 297. K_2CO_3 . | 334. HClO_3 . |
| 298. KHCO_3 . | 335. HClO_4 . |
| 299. KO.HO.CO . | 336. HNO . |
| 300. $\text{Na}_2\text{H}_2\text{CO}_4$. | 337. HNO_2 . |
| 301. NaHCO_3 . | 338. HNO_3 . |
| 302. K_2SO_3 . | 339. H_3NO_4 . |
| 303. $(\text{KO})_2\text{SO}$. | 340. HONO_2 . |
| 304. $\text{SO}(\text{OK})_2$. | 341. $(\text{HO})_3\text{NO}$. |
| 305. FeSO_4 . | 342. Hg_2HNO_4 . |
| 306. FeO_2SO_2 . | 343. HgNO_3 . |
| 307. FeH_2SO_5 . | 344. HgONO_2 . |
| 308. $\text{FeO}_2(\text{HO})_2\text{SO}$. | 345. $\text{Hg}(\text{NO}_3)_2$. |
| 309. SO_2FeO_2 . | 346. $\text{HgO}_2(\text{NO}_2)_2$. |
| 310. ZnO_2SO_2 . | 347. ClHgNH_2 . |
| 311. ZnH_2SO_5 . | 348. H_4NONO_2 . |
| 312. HPH_2O_2 . | 349. H_4NOH . |
| 313. HOPH_2O . | 350. H_4NCl . |
| 314. $(\text{HO})_2\text{PHO}$. | 351. HgH_2NCl . |
| 315. H_3PO_4 . | 352. $\text{K}_2\text{C}_4\text{H}_4\text{O}_6$. |
| 316. $(\text{HO})_3\text{PO}$. | 353. $(\text{KOO})_2\text{C}_2\text{H}_4\text{O}_2$. |
| 317. $\text{PO}(\text{OH})_3$. | 354. $\text{HC}_2\text{H}_3\text{O}_2$. |
| 318. Na_2HPO_4 . | 355. HO.CO.CH_3 . |
| 319. $(\text{NaO})_2\text{HO.PO}$. | 356. $\text{H}_3\text{C.OC.OH}$. |
| 320. $\text{H}_2\text{C}_2\text{O}_4$. | 357. $\text{Fe}(\text{PH}_2\text{O}_2)_3$. |
| 321. $(\text{HOCO})_2$. | 358. FePO_4 . |
| 322. $(\text{COOH})_2$. | 359. ClNO . |
| 323. $(\text{COOK})_2$. | 360. CaH_4SO_6 . |
| 324. $(\text{KO})_2(\text{CO})_2$. | 361. $\text{HOPbC}_2\text{H}_3\text{O}_2$. |
| 325. $\text{H}_2\text{P}_4\text{O}_7$. | 362. $\text{AlNa}(\text{SO}_4)_2$. |

CHAPTER XI.

CHEMICAL REACTIONS.

109. Chemical reactions are changes by which molecules of any kind are transformed into molecules of any other kind.

All chemical reactions are atomic rearrangements.

Two or more free atoms may combine to form a molecule, or molecules may be decomposed into free atoms, or a molecule may undergo a rearrangement of its inter-atomic linking, or one molecule may be split up into two or more molecules of a different kind, or two or more molecules may react with each other to form new and different molecules.

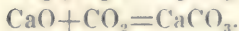
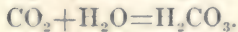
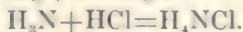
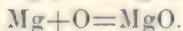
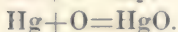
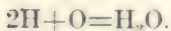
Ionization is quite unlike the changes here referred to, for ions are not molecules. The dissociation of the ions from each other continues while the dissociated substance remains dissolved; no ion can be removed from the solution; and the positive and negative ions, instead of forming any new kind of molecules, are reunited when the solvent which causes the dissociation is removed. (See par. 112.)

110. The **factors** of chemical reactions are the molecules which undergo change or are transformed into other substances.

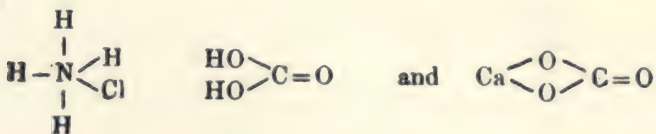
The **products** are the new substances formed.

111. A **synthesis** or synthetic reaction is the direct **combination** of two or more factors to form but one product.

The following are examples:



In the three last examples the student should observe that the products are formed not merely by adding the factors together but by a rearrangement of the atomic linking. Thus when H_3N and HCl form H_4NCl the Cl becomes connected with N instead of with H; when CO_2 and H_2O form H_2CO_3 the product contains two groups of OH; and when CaO and CO_2 form CaCO_3 the Ca becomes directly united to two oxygen atoms instead of only one. The structural formulas of the products are:



112. Decomposition means the splitting up of one molecule into two or more other kinds of molecules. (Decomposition is often called dissociation, but that term is now employed to describe the temporary dissociation of the ions of molecules by solution.)

The following are examples of decomposition:

CaCO_3 may be split up into CaO and CO_2 .

HgO may be split up into Hg and O .

H_2O_2 may be split up into H_2O and O .

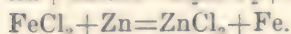
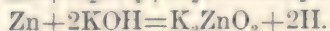
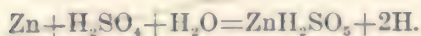
H_4NONO may be split up into $2\text{H}_2\text{O}$ and N .

$\text{Mg}_5(\text{OH})_2(\text{CO}_3)_4$ may be split up into $5\text{MgO} + \text{H}_2\text{O} + 4\text{CO}_2$.

Electrolysis is decomposition caused by an electric current, as when water is decomposed into hydrogen and oxygen. This electrolytic dissociation differs from ionization (par. 109) in that the dissociated atoms or atomic groups do not remain in a state of dissociation but form new molecules. Thus in the electrolysis of water the molecules of water are decomposed into hydrogen atoms and oxygen atoms which respectively form molecules of hydrogen and molecules of oxygen, while by ionization the water splits up into ions of H and OH .

113. Displacement reactions are those in which one element

is liberated from a compound by another element which takes its place, as, for example:

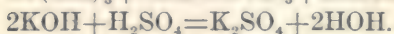
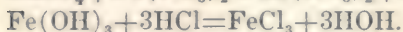
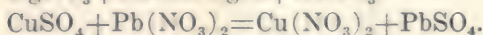
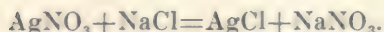


[When the atoms of one element displaced by atoms of other elements are not set free the reaction is called **substitution**, as in $\text{H}_4\text{C} + 2\text{Cl} = \text{H}_3\text{CCl} + \text{HCl}$.]

114. Metatheses, or metathetic reactions, are chemical reactions between two factors consisting of compound molecules which form two products by a mutual interchange of their ions or radicals. Such reactions are also commonly called **double decomposition**.

No changes of atomic combining value occur in any metathesis.

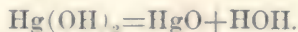
The following reactions are metatheses or double decompositions:



Metathetic reactions are sometimes attended by the immediate dissociation of one of the products, with the result that more than two ultimate products are obtained, as may be seen in the following examples:

$\text{K}_2\text{CO}_3 + 2\text{HCl} = 2\text{KCl} + \text{HOH} + \text{CO}_2$, which may be regarded as the outcome of $\text{K}_2\text{CO}_3 + 2\text{HCl} = 2\text{KCl} + \text{H}_2\text{CO}_3$ and the splitting up of H_2CO_3 into H_2O and CO_2 .

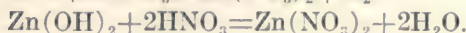
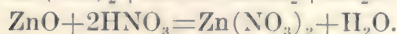
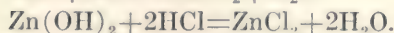
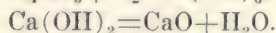
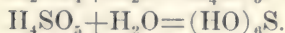
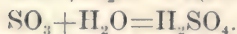
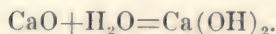
$\text{HgCl}_2 + 2\text{KOH} = \text{HgO} + 2\text{KCl} + \text{HOH}$, which may be explained by the assumption that $\text{Hg}(\text{OH})_2$ is hypothetically one of the products of the double decomposition but that it immediately splits up into HgO and HOH —



When one of the factors of a metathesis is water the reac-

tion is called **hydrolysis**. Thus $\text{K}_2\text{CO}_3 + \text{H}_2\text{O} = \text{KHCO}_3 + \text{KOH}$ is a hydrolytic metathesis or double decomposition.

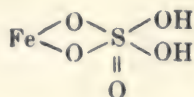
[**Water** is frequently either a factor or a product in chemical reactions of various kinds, as shown by the following examples:



Hydrogen and oxygen are often split off from hydroxyl compounds when heated, the H and O uniting to form water.

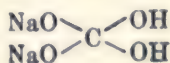
Compounds capable of combining with hydrogen and oxygen (in the proportions in which H and O unite to form water) often do so when brought in contact with water, thus decomposing the H_2O .

It is quite probable that many compounds supposed to be hydrates (to contain H_2O) do not contain any water at all but contain OH instead, and that many hydrates contain less water than they have been represented to contain. Thus the compound formerly represented as $\text{FeSO}_4 + \text{H}_2\text{O}$ is now believed to be FeH_2SO_5 ,

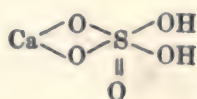


and the hydrate formerly represented as $\text{FeSO}_4 + 7\text{H}_2\text{O}$ is now written $\text{FeH}_2\text{SO}_5 + 6\text{H}_2\text{O}$.

The so-called monohydrated sodium carbonate, represented as $\text{Na}_2\text{CO}_3 + \text{H}_2\text{O}$, may be $\text{Na}_2\text{H}_2\text{CO}_4$,



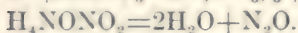
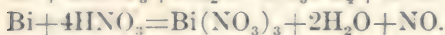
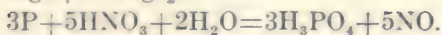
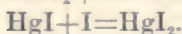
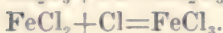
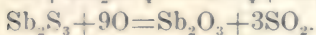
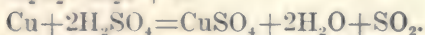
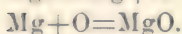
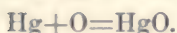
and the dihydrated calcium sulphate, represented as $\text{CaSO}_4 + 2\text{H}_2\text{O}$ may be



When acidic hydroxides and meta-hydroxides are neutralized by bases the composition of the salts formed in the water-solutions is not necessarily identical with that of the solid salt recovered by the evaporation of the solvent, for water may be formed at the same time.]

115. Reactions attended by changes of atomic combining value are called **oxidation and reduction** when the terms "oxidation" and "reduction" are employed in their widest sense. Oxidation and reduction always accompany each other.

Examples of oxidation and reduction are:



[116. Intramolecular reactions or **metastases** are internal rearrangements of the atoms in molecules. One substance may be changed into another without decomposing, retaining its percentage composition and molecular weight, the only change being one of interatomic linking. Such changes are not common. Cyanides and isocyanides afford examples.

Other chemical changes are condensation reactions, such as, for instance, the formation of paraldehyde, $\text{C}_6\text{H}_{12}\text{O}_3$ from three molecules of aldehyde, $\text{C}_2\text{H}_4\text{O}$.

Reactions such as referred to in this paragraph occur in organic chemistry.]

117. Molecules of matter remain unaltered under constant or unchanged conditions. But when exposed to new conditions they may more or less readily undergo change. The new molecules formed are such as resist further change. Heat, light and electricity, changes of pressure, contact with other substances, are among the common causes of chemical changes.

Heat often causes decomposition, when one or more volatile products may be formed.

Light also frequently causes decomposition. But the most common conditions affecting the stability of molecules may be summarized as follows:

118. States of cohesion or "aggregation" of the reacting substances materially influence the direction and extent of chemical reactions.

Solids do not readily react upon each other or upon liquids or gases.

Gases react more freely than solids, but not as freely as liquids.

Solids may be rendered liquid by fusion to facilitate reaction, and gases may be condensed by pressure. But substances in a state of **solution** react most quickly and completely.

119. The formation of molecules of relatively greater stability results from the pairing or coming together of strongly pronounced positive elements or radicals with strongly pronounced negative elements and radicals. This tendency is manifest in the decomposition of the salts of feeble acids by the stronger acids, the tendency of stronger bases to decompose the salts of weaker bases, the removal of chlorine from molecules by means of metals which form chlorides, the decomposition of iodides by bromine, bromides by chlorine, and numerous other reactions commonly observed and generally utilized.

The tendency toward the pairing of the more strongly positive radicals with the more strongly negative radicals present in metatheses may, however, be nullified by the formation of volatile products or of products which are insoluble or less soluble than either of the factors. (See par. 124).

120. The greater intensity of chemical combining energy exhibited by elements in the **nascent state**—that is, at the moment of their liberation from compounds—is exemplified by the chemical solution of gold in “aqua regia,” the great reducing power of nascent hydrogen, and the prompt oxidizing power of ozone and of hydrogen dioxide. This greater intensity of chemical action **in statu nascendi** applies also to compound radicals, as may be seen from the fact that a mixture of potassium nitrate and sulphuric acid “attacks” organic substances more vigorously than nitric acid; that ethyl acetate is more readily formed from a mixture of alcohol, sulphuric acid and sodium acetate than from alcohol and acetic acid, etc.

121. The term “predisposing affinity” has been used to express the tendency toward the formation of acidic radicals in the presence of strong bases, and the formation of basic radicals in the presence of strong acids, as illustrated by the following examples:

Potassium nitrate may be produced out of refuse animal matter. The nitrogen in the nitrogen compounds of animal matter has a combining value of -3 . But **in the presence of potassium carbonate** the nitrogen is oxidized by the oxygen of the air so that KNO_3 is formed.

The manganese in MnO_2 has a combining value of $+4$. Heated with KOH it forms potassium manganate; but with acids it forms manganous salts.

Chromous compounds contain divalent chromium. In the presence of acids they form chromic salts in which the Cr is trivalent; but in the presence of alkalies they form chromates in which the Cr is hexavalent.

Potassium chlorate is formed by the action of Cl on KOH because KCl is the principal product (see par. 119), being a very stable compound, and the chlorate results from the presence of the oxygen of the KOH and the predisposing affinity of K for all acid-radicals.

122. The **volatility** of one or more of the products of a chemical reaction at the temperature at which the reaction takes place has a decided influence upon the result.

Chemical reactions are facilitated and rendered more complete when one or more of the products are gases.

Chlorine, the nitrate radical (ONO_2) and bromine are all more powerful negative radicals than the sulphate radical (O_2SO_2) and this fact is expressed by the common statement that hydrochloric acid, nitric acid and hydrobromic acid are stronger acids than sulphuric acid; but sulphuric acid decomposes chlorides, nitrates and bromides when heated with them because hydrogen chloride, nitric acid and hydrogen bromide are more volatile than sulphuric acid.

123. Solution has a decided influence upon chemical action.

Practically insoluble solids may react upon each other in water if only one product is formed and that is water-soluble, as when iron and iodine form ferrous iodide.

Metals decompose acids and "dissolve" in the form of salts or halides if the metallic compound formed is soluble either in the acid or in the water in which the acid is contained in solution. Concentrated nitric acid is not acted upon by iron because nitrate of iron is insoluble in strong nitric acid; but iron acts rapidly on diluted nitric acid because iron nitrate is readily soluble in water and in dilute nitric acid.

124. The velocity and completeness of chemical reactions are greatly increased or facilitated by the removal of one or more of the products as rapidly as formed.

Metathetic reactions between soluble factors resulting in soluble products do not proceed to completion because none of the products is removed from the arena of chemical action.

In the production of chemical compounds those processes are generally most satisfactory which result in the formation of quickly and completely separable products.

If the products are two the results are as a rule most satisfactory: 1. When the factors are used in the form of water-solutions and one of the products is soluble while the other is insoluble in water; 2, when one of the products is a gas and the other a liquid or solid; 3, when one product is a liquid and the other a solid insoluble in that liquid; 4, when one of the products is water; and 5, when the two products differ greatly in solubility so that they may be separated from each other by evaporation and crystallization.

An interesting example of the practical application of double decomposition in which both of the products as well as both factors are soluble is afforded in the manufacture of potassium nitrate from NaNO_3 and KCl , which are boiled together. The NaCl begins to crystallize out as rapidly as formed when the solution of the KNO_3 becomes sufficiently concentrated, and at the end of the process a saturated solution of KNO_3 is obtained nearly free from NaCl , which is not soluble in that saturated solution.

125. Whenever by double decomposition between compounds in solution **an insoluble or a less soluble compound** can be formed, then that insoluble or less soluble compound will always be obtained.

The less soluble or insoluble product is **precipitated** and this phenomenon is called **precipitation**. The precipitate is removed from the arena of chemical action which, therefore, proceeds to completion.

Chemical compounds insoluble in water, or nearly, so, are, therefore, generally produced by metatheses between water-soluble factors in solution.

Compounds insoluble in alcohol, ether, or other liquids, may be made on the same principle.

No chloride of any kind, in solution, can be added to nitrate of silver solution without producing a precipitate of silver chloride because AgCl is insoluble.

A solution of a sulphate can not be mixed with a solution of barium nitrate without precipitation because barium sulphate is insoluble and must, therefore, be formed.

Analysis by precipitation, both qualitative and quantitative, and certain processes of purification depend upon the completeness of reactions of this character.

Quinine hydrochloride, ammonium salicylate and quinine salicylate are all soluble in alcohol, but ammonium chloride is insoluble in that liquid; quinine salicylate in alcoholic solution can, therefore, be made by mixing alcohol solutions of quinine hydrochloride and ammonium salicylate the ammonium chloride being precipitated.

When any acid is added to an ether solution of any alkaloid the salt formed by that acid with that alkaloid will be precipitated because all alkaloidal salts are insoluble in ether.

Insoluble compounds are usually made by double decomposition resulting in precipitation, water-solutions of the factors being used and the by-products soluble.

126. Water-soluble metallic salts are frequently made by **saturating** or **neutralizing** acids with metals or with their oxides, hydroxides or carbonates. It, therefore, often happens that materials insoluble in water are employed to make soluble salts by chemical solution.

127. Volatile liquid compounds and **gases** are often produced by double decomposition and **distillation**.

Volatile solids are sometimes made by double decomposition and **sublimation**.

128. Dissociation is often effected by the **calcination** of metallic salts, the principal products being metallic oxides and the by-products gases. The term calcination is derived from the word **calx**, lime, which is produced by strongly heating calcium carbonate. The oxides of metals can be made by calcination from not only carbonates, but from nitrates, sulphates, hydroxides, oxalates and other compounds yielding volatile by-products.

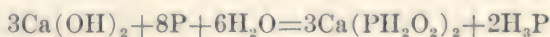
129. Fusible solids are sometimes made by syntheses, as when the sulphides of iron and copper are produced by melting them with sulphur. Iodide of sulphur and iodide of arsenic are also made by fusing the elements together.

130. All chemical reactions in which free elements are either factors or products are reactions of **oxidation and reduction** because all free elements have a valence expressed by 0 while all atoms in combination have bonds, whatever may be the algebraic sum of those bonds.

In the reaction $\text{Hg} + \text{O} = \text{HgO}$ the mercury atom changes its combining value from 0 to +2, and the oxygen atom changes from 0 to -2.

In the reaction $\text{HgO} = \text{Hg} + \text{O}$ the mercury changes from +2 to 0 and the oxygen from -2 to 0.

In the reaction—



six of the phosphorus atoms act as reducing agents and the remaining two phosphorus atoms act as oxidizing agents.

131. The **relative proportions** of the reagents or factors of a chemical reaction materially affect their results.

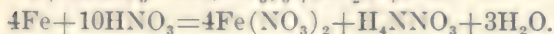
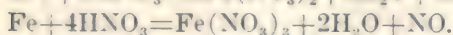
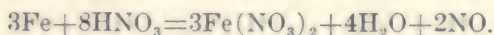
By "relative proportions" we do not mean relative weights but relative numbers of molecules.

The proportional numbers of molecules of the factors of a metathesis are found from the equation representing the reaction and showing the products formed.

As the elements combine with each other in definite proportions according to their respective atomic weights, or fixed mass units of chemical combination, it follows that the factors of any chemical reaction must be taken in definite proportions according to their molecular weights and the number of molecules required of each to produce a complete interchange must be such as shall leave no remainder of either of the factors.

But in order to find the proportions of the factors we must first know the products.

The radical differences which may result from different proportions are illustrated by the following equations:—

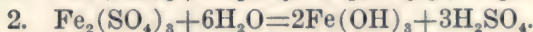
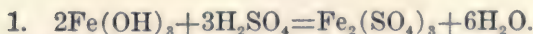
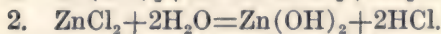
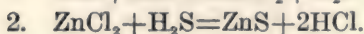
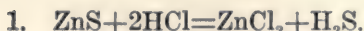


When barium sulphate, which is insoluble in water, is acted upon by a solution of sodium carbonate, portions of the two salts are decomposed so that the solution will contain both sodium sulphate and sodium carbonate while the insoluble solid matter will become a mixture of barium carbonate and barium sulphate. But this double decomposition soon ceases unless the solution of sodium salts be removed from time to time and replaced with fresh portions of solution of sodium carbonate. Repeated treatment with fresh portions of sodium carbonate will, however, finally convert the whole quantity of barium sulphate into barium carbonate.

Experience has demonstrated that the exact proportions required by theory according to the chemical equations do not always result in the complete decomposition of both or all of the factors. In order to insure the complete decomposition of one of the factors of a metathesis it is often necessary to use a somewhat larger proportion of the other factor than that called for by the equation. In a metathesis resulting in the formation of an insoluble metallic compound the rule is that the factor which constitutes the metal must be completely decomposed in order to obtain a pure product, and this requires that the other factor should be used in excess of the theoretical proportion.

The influence of an excess of one factor over the other, as here described, is often called "mass action" or the influence of mass, but that is clearly erroneous for the excess is not necessarily a relatively larger mass of one factor than of the other but a larger proportion than that indicated by the equation representing a normal reaction.

132. Reversible reactions. Chemical reactions are sometimes reversible, as illustrated by the following equations:



The reactions numbered 1 are normal reactions which proceed rapidly and to completion when the proportions of the reacting molecules are those given in the equations; but the reactions numbered 2 take place only to a very slight extent,

possess only a theoretical interest, and may be entirely ignored in practical laboratory operations when proper proportions of the reacting factors are employed.

133. When chemical reactions are produced by bringing two or more substances into contact with each other it often happens that not one but two or more reactions result. When the initial, intermediate and final reactions are known the student will find it interesting and profitable to trace them. But in a great majority of cases the most useful and expeditious method of representing reactions by equations is to consider only the factors and final products, ignoring intermediate products and making one equation represent the whole series of changes whenever practicable. In fact, this method is generally not only practicable but easier than any other and, therefore, almost invariably followed. (See par. 131.)

CHAPTER XII.

CHEMICAL EQUATIONS.

134. A **chemical equation** is an expression of a chemical reaction by means of the symbols or symbolic formulas of its factors and products, showing in its **first member** the kinds and relative numbers of atoms or molecules of the factors and in the **second member** the kinds and numbers of the atoms or molecules of the products.

135. When free or uncombined elements are included among either the factors or the products, they may be represented by either their atoms or their molecules. Both methods are employed. But the molecular formulas of most of the elements are unknown and it is, moreover, easier in any case to write atoms than molecules.

136. When solids, liquids and gases are all concerned in a reaction the solids are usually written first and the gases last.

When only solids are represented that factor which supplies the positive ion or radical of the principal product should be placed at the beginning of the first member of the equation and that product itself should be written first in the second member.

137. When either factors or products are hydrates the water may be omitted from the formulas except when the equation is to be made the basis for stoichiometric computations. When stoichiometric calculations are made it is, of course, necessary to take into account the water contained in both materials and products.

138. One of the most important requisites in devising and formulating a process for the production of a chemical compound is the construction of the chemical equation which correctly indicates the materials required, the products obtained, and the quantities of each. The computation of these quantities is called **stoichiometry**.

139. In order to properly **balance chemical equations** it is necessary to know not only the symbols and formulas of elements and compounds concerned in the reactions but also the combining values and polarities of the atoms and radicals which change places.

The combining values of elements having a variable valence are found from the constant valences of negative elements and compound radicals or from any elements known to have a constant valence.

The kinds and numbers of the atoms must be the same in both members of the equation and the algebraic sum of the units of atomic combining value must be 0 in every molecule.

140. The simplest equations to write are those representing reactions of **dissociation** because the factor is only one and is divided into the products.

141. Syntheses are nearly as simple because the factors are in most cases added together and the molecular formulas of the products put in proper form.

142. Metathetic reactions in which the factors are two offer no difficulty because the radicals of the factors simply change places. If all the ions or radicals have identical valences the mutual interchange which takes place may be likened to an exchange of horses by two riders meeting each other. Such a simple interchange is shown in the equation—



When the ions or radicals which exchange places have different combining values: **Multiply the molecule of the first factor by the total valence units of the negative ion or radical of one molecule of the second factor, and the molecule of the second factor by the total valence units of the negative radical of one molecule of the first factor.** The number of molecules required of each factor having been thus found it only remains to transpose the ions or radicals in order to find the respective numbers of the molecules of the products.

This method is exemplified in the following:

Al(OH)_3 and H_2SO_4 will form $\text{Al}_2(\text{SO}_4)_3$ and HOH . The first factor is Al(OH)_3 which contains the monovalent nega-

tive radical OH three times; we, therefore, take 3 molecules of the second factor, H_2SO_4 . The negative radical of the second factor is the divalent SO_4 which is contained only once in the molecule H_2SO_4 ; we, therefore, take 2 molecules of the first factor, $\text{Al}(\text{OH})_3$. The equation thus becomes:



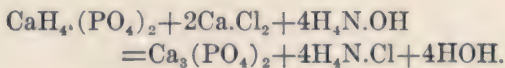
In $\text{Pb}(\text{NO}_3)_2 + \text{CuSO}_4 = \text{PbSO}_4 + \text{Cu}(\text{NO}_3)_2$ we find that equal numbers of the molecules of the factors are required because $(\text{NO}_3)_2$ must have 2 valence units and the SO_4 also has 2 bonds.

In $\text{Fe}_2(\text{SO}_4)_3 + 6\text{NaOH} = 2\text{Fe}(\text{OH})_3 + 3\text{Na}_2\text{SO}_4$ we can see that one molecule of $\text{Fe}_2(\text{SO}_4)_3$ is required because only one hydroxyl group is contained in the NaOH, but that the NaOH must be taken six times because $(\text{SO}_4)_3$ must have six bonds.

Equations representing double decomposition are sometimes less simple than those here cited as examples, but in all reactions where there is no change of algebraic combining value of any atom the balancing of the equations, when the molecular formulas of factors and products are known, is a task easily mastered by sufficient practice.

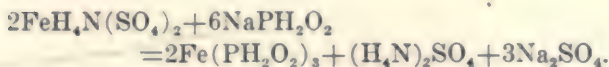
See also Chapter XV.

143. When the factors are more than two; or the products more than two, the problem is less simple; but if the radicals which exchange places remain the same in the products as in the factors it is not difficult to solve it, as the following examples indicate:



Here we find the molecule $\text{Ca}_3(\text{PO}_4)_2$ among the products. This contains the group PO_4 twice. Hence one molecule of the factor $\text{CaH}_4(\text{PO}_4)_2$ is sufficient; but two molecules of the factor CaCl_2 are necessary to furnish the additional two atoms of Ca. But the product H_4NCl contains only one chlorine atom; hence two molecules of CaCl_2 suffice to furnish the Cl for 4 molecules of H_4NCl , and four molecules of H_4NOH are necessary for the 4 molecules of H_4NCl .

A somewhat more complicated problem is—



In this reaction the group SO_4 which is divalent is contained in the $\text{FeH}_4\text{N}(\text{SO}_4)_2$ twice, and the group PH_2O_2 which is monovalent is contained in the NaPH_2O_2 only once; but in the product $\text{Fe}(\text{PH}_2\text{O}_2)_3$ the group PH_2O_2 is contained three times. It is evident, however, that three molecules of NaPH_2O_2 would furnish three sodium atoms—an odd number—while Na_2SO_4 contains an even number. But 6 molecules of NaPH_2O_2 and 2 molecules of $\text{FeH}_4\text{N}(\text{SO}_4)_2$ must produce 2 molecules of $\text{Fe}(\text{PH}_2\text{O}_2)_3$ and 3 molecules of Na_2SO_4 .

144. Other reactions occur in which the radicals contained in factors and products are changed, but in which there is no change of algebraic combining value of any atom (or, in other words, no “oxidation and reduction”). The following examples will suffice:

- a. $\text{As}_2\text{O}_3 + 4\text{KOH} = 2\text{K}_2\text{AsHO}_3 + \text{HOH}.$
- b. $\text{As}_2\text{O}_3 + 2\text{K}_2\text{CO}_3 + \text{HOH} = 2\text{K}_2\text{AsHO}_3 + 2\text{CO}_2.$
- c. $\text{As}_2\text{O}_3 + 3\text{HOH} = 2\text{H}_2\text{AsHO}_3.$
- d. $\text{Ca}_3(\text{PO}_4)_2 + 4\text{HCl} = \text{CaH}_4(\text{PO}_4)_2 + 2\text{CaCl}_2.$
- e. $2\text{Bi}(\text{NO}_3)_3 + 3\text{Na}_2\text{CO}_3 = (\text{OBi})_2\text{CO}_3 + 6\text{NaNO}_3 + 2\text{CO}_2.$
- f. $\text{Fe}_2(\text{SO}_4)_3 + 2\text{Na}_2\text{HPO}_4 + 2\text{NaC}_2\text{H}_3\text{O}_2 \\ = 2\text{FePO}_4 + 3\text{Na}_2\text{SO}_4 + 2\text{HC}_2\text{H}_3\text{O}_2.$
- g. $\text{HgCl}_2 + 2\text{KOH} = \text{HgO} + 2\text{KCl} + \text{HOH}.$

EXAMPLES.

Write equations representing the dissociation of the following substances under the influence of heat:

- | | |
|---|--|
| 371. $\text{HgO}.$ | 377. $\text{FeH}_2\text{SO}_5.$ |
| 372. $\text{CaCO}_3.$ | 378. $\text{Ca}(\text{OH})_2.$ |
| 373. $\text{Cu}(\text{NO}_3)_2.$ | 379. $2\text{ZnCO}_3 \cdot 3\text{Zn}(\text{OH})_2.$ |
| 374. $\text{FeC}_2\text{O}_4.$ | 380. $\text{Na}_2\text{HPO}_4.$ |
| 375. $\text{Mg}_5(\text{OH})_2(\text{CO}_3)_4 + 5\text{H}_2\text{O}.$ | 381. $\text{Pb}(\text{NO}_3)_2.$ |
| 376. $\text{Zn}_3(\text{OH})_2(\text{CO}_3)_2.$ | 382. $\text{HgNO}_3.$ |

Write the reactions occurring in the combustion of the following named substances in oxygen or in air:

- 383. Carbon (complete combustion).
- 384. Carbon (incomplete combustion).
- 385. CO.
- 386. Hydrogen.
- 387. Phosphorus.
- 388. Sulphur.
- 389. Magnesium.
- 390. Zinc.
- 391. CH_4 .
- 392. $\text{C}_2\text{H}_5\text{OH}$.

Write the equations representing the syntheses between the following named factors:

- 393. Iron and iodine in water.
- 394. Arsenic and I melted together.
- 395. Sulphur and I melted together.
- 396. Iron and S melted together.
- 397. Copper and sulphur, heated.
- 398. Mercury and sulphur, triturated.
- 398. Mercury and iodine, triturated.

Write the reactions representing the action of HCl upon:

- | | |
|-------------------------------|---|
| 399. Fe. | 408. CaCO_3 . |
| 400. Zn. | 409. $\text{Al}(\text{OH})_3$. |
| 401. Al. | 410. K_2CO_3 . |
| 402. HgO . | 411. AgCN . |
| 403. KOH . | 412. FeS . |
| 404. ZnO . | 413. CaSO_3 . |
| 405. Sn. | 414. $\text{Fe}(\text{OH})_3$. |
| 406. H_3N . | 415. FePO_4 . |
| 407. H_4NOH . | 416. $\text{H}_4\text{NHCO}_3\text{H}_4\text{NNH}_2\text{CO}_2$. |

Write the equations representing the action of acids on metals as follows:

- 417. H_2SO_4 on Zn.
- 418. H_2SO_4 on Fe.
- 419. Hot strong H_2SO_4 on Cu.

420. Hot strong H_2SO_4 on Hg.
 421. Hot strong H_2SO_4 on Ag.
 422. Strong nitric acid on tin.
 423. Strong nitric acid on antimony.

Warm diluted nitric acid on :

- | | |
|----------|----------|
| 424. Fe. | 429. Ag. |
| 425. Zn. | 430. Bi. |
| 426. Ni. | 431. Hg. |
| 427. Pb. | 432. As. |
| 428. Cu. | |

Complete the following equations:

433. $\text{?K}_2\text{CO}_3 + \text{?HNO}_3 =$
 434. $\text{?BaCO}_3 + \text{?HCl} =$
 435. $\text{?NaHCO}_3 + \text{?HNO}_3 =$
 436. $\text{?Al(OH)}_3 + \text{?H}_2\text{SO}_4 =$
 437. $\text{?PbO} + \text{?HNO}_3 =$
 438. $\text{?4MgCO}_3 \cdot \text{Mg(OH)}_2 + \text{?H}_2\text{SO}_4 =$
 439. $\text{?Li}_2\text{CO}_3 + \text{?HBr} =$
 440. $\text{?Fe} + \text{?H}_3\text{PO}_4 =$
 441. $\text{?KBr} + \text{?H}_2\text{SO}_4 =$
 442. $\text{?NaCl} + \text{?H}_2\text{SO}_4 =$
 443. $\text{?KNO}_3 + \text{?H}_2\text{SO}_4 =$
 444. $\text{?FeS} + \text{?H}_2\text{SO}_4 =$
 445. $\text{?Na}_2\text{B}_4\text{O}_7 + \text{?HNO}_3 =$
 446. $\text{H}_2\text{SO}_4 + \text{H}_2\text{O} =$
 447. $\text{H}_2\text{SO}_4 + 2\text{H}_2\text{O} =$
 448. $\text{CaO} + \text{H}_2\text{O} =$
 449. $\text{?As}_2\text{O}_3 + \text{?H}_2\text{O} =$
 450. $\text{?Bi(NO}_3)_3 + \text{?H}_2\text{O} =$
 451. $\text{?HgSO}_4 + \text{?H}_2\text{O} =$
 452. $\text{?Zn} + \text{?KOH} =$
 453. $\text{?H}_4\text{NCl} + \text{?KOH} =$
 454. $\text{?H}_4\text{NCl} + \text{?K}_2\text{CO}_3 =$
 455. $\text{?(H}_4\text{N)}_2\text{SO}_4 + \text{?NaOH} =$
 456. $\text{?ZnCl}_2 + \text{?KOH} =$
 457. $\text{?HgCl} + \text{?Ca(OH)}_2 =$
 458. $\text{?HgCl}_2 + \text{?Ca(OH)}_2 =$
 459. $\text{?FeCl}_3 + \text{?H}_4\text{NOH} =$

460. $?AlK(SO_4)_2 + ?Na_2CO_3 =$
461. $FeCl_2 + Cl =$
462. $2FeCl_3 + Fe =$
463. $H_2O + K =$
464. $H_2O + 2Cl =$
465. $?FeCl_3 + ?KI =$
466. $FeCl_2 + Zn =$
467. $?AgNO_3 + ?FeCl_2 =$
468. $?AgNO_3 + ?NaCl =$
469. $?BaCl_2 + ?K_2SO_4 =$
470. $?Ba(NO_3)_2 + ?CaHSO_4 =$
471. $AgCN + HBr =$
472. $?Ca(PH_2O_2)_2 + ?H_2C_2O_4 =$
473. $?H_4NCl + ?Ca(OH)_2 =$
474. $FeBr_2 + 2FeBr_3 + 8H_4NOH =$
475. $?Sb_2O_3 + ?HCl =$
476. $?Sb_2S_3 + ?HCl =$
477. $?Ba(NO_3)_2 + ?(H_4N)_2CO_3 =$
478. $2Ba(C_2H_3O_2)_2 + H_2O + K_2Cr_2O_7 = 2BaCrO_4 +$
479. $OBiNO_3 + H_3C_6H_5O_7 = BiC_6H_5O_7 +$
480. $OBiNO_3 + H_2O + H_4NOH = Bi(OH)_3 +$
481. $?OBiNO_3 + H_2O + ?NaOH = Bi_2O_3 +$
482. $2Bi(NO_3)_3 + 3Na_2CO_3 + H_2O = (OBi)_2CO_3 + H_2O +$
483. $OBiNO_3 + KI = KNO_3 +$
484. $?H_4NBr + ?CaO =$
485. $2FeI_2 + 2I + ?Ca(OH)_2 = ?CaI_2 + Fe_2O_3 +$
486. $Ca_3(PO_4)_2 + 4HCl = 2CaCl_2 +$
487. $Na_2HPO_4 + CaCl_2 =$
488. $?K_2Cr_2O_7 + ?H_2SO_4 = ?CrO_3 + ?KHSO_4 + ?H_2O.$
489. $?Cr_2(SO_4)_3 + ?H_4NOH =$
490. $?CuSO_4 + ?Ba(C_2H_3O_2)_2 =$
491. $?FeSO_4 + ?NaHCO_3 =$
492. $?FeH_2SO_5 + ?NaHCO_3 =$
493. $?Fe(OH)_3 + ?H_3C_6H_5O_7 = ?FeC_6H_5O_7 +$
494. $?KHC_4H_4O_6 + ?Fe(OH)_3 = OFeKC_4H_4O_6 +$
495. $?(FeH_4N(SO_4)_2 + 12H_2O) + ?(NaPH_2O_2 + H_2O)$
 $= ?Fe(PH_2O_2)_3 +$
496. $?FeH_2SO_5 + ?H_2C_2O_4 = ?FeC_2O_4 +$
497. $?FeH_2SO_5 + ?Na_2HPO_4 = ?Fe_3(PO_4)_2 +$

498. $\text{?Fe}_2(\text{SO}_4)_3 + \text{?Na}_2\text{HPO}_4 + \text{?NaC}_2\text{H}_3\text{O}_2$
 $= \text{?FePO}_4 + \text{?Na}_2\text{SO}_4 +$
499. $\text{?Fe}_2(\text{SO}_4)_3 + \text{?Na}_4\text{P}_2\text{O}_7 =$
500. $\text{?Fe} + \text{?H}_2\text{SO}_4 + \text{?H}_2\text{O} = \text{?(FeH}_2\text{SO}_5 + 6\text{H}_2\text{O}) +$
501. $\text{?(FeH}_2\text{SO}_5 + 6\text{H}_2\text{O}) + \text{?H}_2\text{SO}_4 + \text{?HNO}_3$
 $= \text{?[Fe}_4\text{O}(\text{SO}_4)_5] + \text{?H}_2\text{O} + \text{?NO.}$
502. $\text{?(FeH}_2\text{SO}_5 + 6\text{H}_2\text{O}) + \text{?H}_2\text{SO}_4 + \text{?HNO}_3$
 $= \text{?Fe}_2(\text{SO}_4)_3 + \text{?H}_2\text{O} + \text{?NO.}$
503. $\text{?Fe}_2(\text{SO}_4)_3 + \text{?(H}_4\text{N})_2\text{SO}_4 + \text{?H}_2\text{O}$
 $= \text{?[FeH}_4\text{N}(\text{SO}_4)_2 + 12\text{H}_2\text{O}].$
504. $\text{?PbO} + \text{?HC}_2\text{H}_3\text{O}_2 + \text{?H}_2\text{O} = \text{?[Pb(C}_2\text{H}_3\text{O}_2)_2 + 3\text{H}_2\text{O}].$
505. $\text{?Pb(NO}_3)_2 + \text{?Na}_2\text{CO}_3 + \text{?H}_2\text{O}$
 $= \text{?PbCO}_3 \cdot \text{Pb(OH)}_2 + \text{?NaNO}_3 + \text{?CO}_2$
506. $\text{?Pb(NO}_3)_2 + \text{?K}_2\text{Cr}_2\text{O}_7 + \text{?H}_2\text{O}$
 $= \text{?PbCrO}_4 + \text{?KNO}_3 + \text{?HNO}_3$
507. $\text{?Pb(C}_2\text{H}_3\text{O}_2)_2 + \text{?KI} = \text{PbI}_2 +$
508. $\text{?[Pb(C}_2\text{H}_3\text{O}_2)_2 + 3\text{H}_2\text{O}] + \text{?PbO} = \text{?HOPbC}_2\text{H}_3\text{O}_2 + \text{?H}_2\text{O}$
509. $\text{?Li}_2\text{CO}_3 + \text{?H}_3\text{C}_6\text{H}_5\text{O}_7 + \text{?H}_2\text{O} = \text{?(Li}_3\text{C}_6\text{H}_5\text{O}_7 + 4\text{H}_2\text{O}) +$
510. $\text{?MgSO}_4 + \text{?Na}_2\text{CO}_3 + \text{?H}_2\text{O}$
 $= \text{?[MgCO}_3 \cdot \text{Mg(OH)}_2 + 4\text{H}_2\text{O}] + \text{?Na}_2\text{SO}_4 + \text{?CO}_2.$
511. $\text{?(4MgCO}_3 \cdot \text{Mg(OH)}_2) + \text{?H}_3\text{C}_6\text{H}_5\text{O}_7$
 $= \text{?Mg}_3(\text{C}_6\text{H}_5\text{O}_7)_2 + \text{?H}_2\text{O} + \text{?CO}_2.$
512. $\text{?(MnSO}_4 + 4\text{H}_2\text{O}) + \text{?(Na}_2\text{HPO}_4 + 12\text{H}_2\text{O})$
 $= \text{?[Mn}_3(\text{PO}_4)_2 + 4\text{H}_2\text{O}] + \text{?(Na}_2\text{SO}_4 + 10\text{H}_2\text{O})$
 $+ \text{?H}_2\text{SO}_4 + \text{?H}_2\text{O.}$
513. $\text{?HgSO}_4 + \text{?NaCl} = \text{?Na}_2\text{SO}_4 + \text{?}$
514. $\text{?K}_4\text{Fe(CN)}_6 + \text{?FeCl}_3 = \text{?[Fe}_4(\text{Fe(CN)}_6)_3] + \text{?KCl.}$
515. $\text{?[Fe}_4(\text{Fe(CN)}_6)_3] + \text{?HgO} + \text{?H}_2\text{O}$
 $= \text{?Hg(CN)}_2 + \text{?[Fe(OH)}_2 \cdot 4\text{Fe(OH)}_3]$
516. $\text{?Hg}_2\text{SO}_4 + \text{?NaCl} = \text{?HgCl} +$
517. $\text{?Pb(C}_2\text{H}_3\text{O}_2)_2 + \text{?KHCO}_3 = \text{?[2PbCO}_3 \cdot \text{Pb(OH)}_2] + \text{?}$
518. $\text{?As}_2\text{O}_3 + \text{?KHCO}_3 = \text{?K}_2\text{AsHO}_3 +$
519. $\text{?K}_2\text{Cr}_2\text{O}_7 + \text{?K}_2\text{CO}_3 = \text{?K}_2\text{CrO}_4 +$
520. $\text{?K}_2\text{CO}_3 + \text{?Ca(OH)}_2 =$
521. $\text{?Ca(PH}_2\text{O}_2)_2 + \text{?K}_2\text{CO}_3 =$
522. $\text{?KHC}_4\text{H}_4\text{O}_6 + \text{?Na}_2\text{CO}_3 = \text{KNaC}_4\text{H}_4\text{O}_6 +$
523. $\text{?Ca(ClO)}_2 + \text{?CaCl}_2 + \text{?Na}_2\text{CO}_3$
 $= \text{?NaClO} + \text{?NaCl} + \text{?CaCO}_3$
524. $\text{?Ca(PH}_2\text{O}_2)_2 + \text{?Na}_2\text{CO}_3 =$

525. $?HC_6H_5SO_4 + ?BaCO_3 = ?Ba(C_6H_5SO_4)_2 +$
526. $?Ba(C_6H_5SO_4)_2 + ?Na_2CO_3 +$
527. $?Ca_3(PO_4)_2 + ?H_2SO_4 = ?CaH_4(PO_4)_2 +$
528. $?CaH_4(PO_4)_2 + ?Na_2CO_3$
 $= ?Ca_3(PO_4)_2 + ?Na_2HPO_4 + ?H_2O + ?CO_2$
529. $?As_2S_3 + ?H_4NOH = ?(H_4N)_2AsHO_3 + ?(H_4N)_2AsHS_3 + ?$
530. $?H_3AsO_4 + ?H_2S =$
-

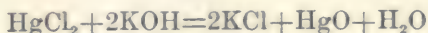
CHAPTER XIII.

OXIDATION AND REDUCTION.

144. There is still some diversity of opinion as to what constitutes "oxidation" and what constitutes "reduction." In its literal and most restricted sense oxidation means combination with oxygen. The formation of MgO by the combustion of the metal, or the formation of CO or CO_2 by burning C in air, or of CO_2 from CO , is clearly oxidation. But a satisfactory definition of the term is difficult even when it is used in that restricted sense.

All agree, however, that in every case of oxidation the element oxidized acquires increased actual combining value.

An increase in the number of oxygen atoms in a molecule, or of the proportion of oxygen by weight, is not oxidation unless it is attended by increased combining value of one or more of the atoms of that molecule. When HgCl_2 is converted into HgO by double decomposition—



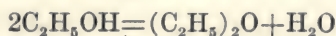
this change is not oxidation although the Hg does enter into combination with oxygen; nor does this reaction involve reduction although the K which in KOH is combined with oxygen enters into combination with Cl instead.

When Na_2SO_3 is mixed with H_2SO_4 a reaction takes place by which the products formed are Na_2SO_4 , SO_2 , H_2O and S . The Na_2SO_3 contains a smaller percentage of oxygen and a less number of atoms of oxygen than Na_2SO_4 , and it contains a smaller percentage of oxygen than we find in SO_2 ; but no chemist would say that the Na_2SO_3 has been oxidized to Na_2SO_4 or to SO_2 . It is, instead, an easily recognized fact that in this reaction one sulphur atom which in the Na_2SO_3 has a combining value of $+6$ suffers reduction to a value of $+4$ in the SO_2 and it is a common saying that the Na_2SO_3 is **reduced**

to SO_2 . The second sulphur atom in the $\text{Na}_2\text{SO}_3\text{S}$ has a combining value of -2 ; that atom is set free and thus acquires a value of 0, which is an **increase instead of a reduction** of combining value.

When Na_2SO_3 in water-solution is boiled with S the product is $\text{Na}_2\text{SO}_3\text{S}$. The Na_2SO_3 contains 48 parts of oxygen in 126, but the $\text{Na}_2\text{SO}_3\text{S}$ contains only 48 parts of oxygen in 158 parts. But it is a fact recognized by all chemists that the Na_2SO_3 is in this reaction oxidized to Na_2SO_4 .

In organic chemistry the removal of hydrogen or the addition of oxygen constitutes oxidation, but this is true only when there are in fact attendant changes of algebraic combining value. But the conversion of alcohol into ether—

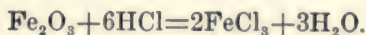


is neither oxidation nor reduction.

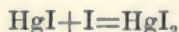
The conversion of FeCl_2 into FeCl_3 by means of Cl is generally admitted to be oxidation and so it is. Yet, no oxygen is concerned in it unless we accept the labored explanation sometimes given that, as this change is effected in a water-solution, it must be that the Cl decomposes the water taking the H from it to form HCl, that the O thus liberated from the H_2O combines with the Fe of the FeCl_2 to form Fe_2O_3 and the Cl of the FeCl_2 also forms HCl, and the Fe_2O_3 and HCl form FeCl_3 and water:



and then



Whether or not this laborious explanation is in accord with the facts, it is quite clear that the equation $\text{FeCl}_2 + \text{Cl} = \text{FeCl}_3$ is intelligible and perfectly analogous with the equation



which is truly as much a case of oxidation as the other and which does not require the presence of any other substance.

The formation of $(\text{HO})_6\text{S}$ from SO_3 is not oxidation although the percentage of oxygen is only 60 in SO_3 while it is over 70 in $(\text{HO})_6\text{S}$. It is not oxidation because the combining value of the sulphur atom remains unchanged, and that value remains unchanged because every unit of oxygen valence is offset by a unit of hydrogen valence, each added oxygen atom being accompanied by two added hydrogen atoms.

145. In its widest sense the term oxidation includes every increase of actual atomic combining value expressed algebraically. Every case of oxidation, as that term is applied in its literal and narrow sense, is also oxidation in its widest sense. In the widest sense of the term there can be no oxidation without corresponding reduction elsewhere, and no reduction without oxidation, for changes of algebraic combining value can not occur singly. That such must be the case may be seen from the fact that all free elements as well as all molecules are assumed to have no valence or a combining value represented by 0 and that the algebraic sum of any number of bonds by which any two atoms are immediately united to each other must also be 0. It is accordingly clearly understood in a general way as a purely mathematical proposition without reference to chemical laws. But it is significant that in every instance the plus-units and minus-units of atomic combining value can be identified according to the relative positions which the combined atoms occupy in the periodic system. In this light the reactions may be understood not only in a general way but in detail.

The use of the term oxidation to designate changes of combining value in cases where oxygen is not one of the elements involved in the reactions is warranted on the ground that such changes, in their very nature, as described, can not take place without some change in that kind of valence which has been referred to as **oxygen valence**, or a fall from 0 to minus value. As hydrogen valence is the valence of any negative element when combined exclusively with one or more positive elements, and is unchangeable, it follows that while we may have a change from one minus value to another in the case of an atom serving as a connecting link between a positive and a negative element (as when carbon atoms intervene between hydrogen

and oxygen, or between hydrogen and chlorine) such a change must necessarily be attended by a change of oxygen valence elsewhere, or a change from 0 to a minus value.

"A change in the quantity of electricity associated with a positive or negative radical is accompanied by an entire change in the properties of the radical. Thus the reactions of diferrion, Fe^{++} , are entirely different from the reactions of triferrion, Fe^{+++} ; and the reactions of permanganion, the ion of the permanganates, MnO_4' , differ greatly from the reactions of manganion, the ion of the manganates MnO_4 ". In connection with such changes in the electric charges of ions, the student will find it useful to remember that addition of a positive charge or removal of a negative charge corresponds to what is generally known as **oxidation** in solution; and that removal of a positive charge or addition of a negative charge corresponds to **reduction**. Thus we are said to oxidize a ferrous salt to a ferric salt when we convert the ion Fe^{++} into Fe^{+++} , or to reduce a permanganate to a manganate when we convert the ion MnO_4' into the ion MnO_4 ". In the first instance a positive charge is removed; in the second a negative charge."*

The combining values of atoms, as expressed algebraically, may change from zero to a plus or minus value; from a plus or a minus value to zero or from a lower to a higher plus value or vice versa. All of these changes may be seen in the reactions here cited, and it will be found that in each case the loss and gain offset each other unit for unit.

When a metal forms an oxide by combustion its combining value rises from zero to a plus value and that of the oxygen falls from zero to a minus value.

When a metal is dissolved in an acid and forms a salt, its combining value rises from zero to a plus value while the replaced hydrogen of the acid falls from a plus value to zero; or, if hydrogen is not liberated, the combining value of the acidic element falls as many units as that of the metal rises.

Nitric acid when used as an oxidizing agent is changed to NO if a sufficient quantity of the reducing agent is present; the nitrogen, therefore, changes its algebraic combining number from +5 to +2 so that its value falls three units. It, there-

*James Walker in his **Introduction to Physical Chemistry**.

fore, raises the combining value of three atoms of silver from zero to $+1$ or that of one atom of bismuth from zero to $+3$; or the nitrogen of five molecules of nitric acid can raise the combining value of three atoms of phosphorus from zero to $+5$, or the nitrogen of two molecules of nitric acid can raise the combining value of three atoms of zinc from zero to $+2$.

When ferrous chloride is changed to ferric by means of hydrogen chloride and nitric acid one molecule of the acid is required for three molecules of FeCl_2 .

When Cu is dissolved in $(\text{HO})_2\text{SO}_2$ the copper atom changes its combining value from zero to $+2$ and the S of one molecule of the acid changes its value from $+6$ to $+4$.

When mercuric chloride in solution is reduced to mercurous chloride by SO_2 one molecule of SO_2 suffices for two molecules of HgCl_2 because the combining value of each mercury atom falls from $+2$ to $+1$ while that of the sulphur atom rises from $+4$ to $+6$.

One molecule of KClO_3 with six molecules of HCl will give us one molecule of KCl and six atoms of free chlorine, because the chlorine atom of the KClO_3 changes its combining value from $+5$ to -1 , a difference of six units, and the six chlorine atoms of the 6HCl change their value from -1 to zero.

The "valence" of each of the nitrogen atoms in H_4NONO_2 is clearly 5; but when the combining values are expressed algebraically that of the first nitrogen atom is -3 and that of the other is $+5$. When the ammonium nitrate is decomposed by heat into water and N_2O one nitrogen atom changes its algebraic combining number from -3 to $+1$, and the other changes its value from $+5$ to $+1$.

The "valence" of the first nitrogen atom in H_4NONO is 5 and that of the other is 3. The algebraic combining numbers are -3 and $+3$. When the ammonium nitrite is decomposed by heat into water and nitrogen one atom of N changes its value from -3 to zero and the other changes its value from $+3$ to zero.

The algebraic combining number of the carbon atom in CH_4 is evidently -4 . When the hydrogen is replaced by chlorine the combining value of the C is raised two units for each

chlorine atom introduced. In order to produce one molecule of monochlormethane two chlorine atoms are required both of which change their combining number from zero to -1 , one of these chlorine atoms producing HCl with the hydrogen atom removed from the methane. The introduction of one negative chlorine atom and the removal of one positive hydrogen atom change the combining number of the C from -4 to -2 .

The equation $\text{C}_2\text{H}_5\text{OH} + 2\text{FeCl}_3 = \text{C}_2\text{H}_4\text{O} + 2\text{FeCl}_2 + 2\text{HCl}$ is explained by the fact that the two iron atoms together lose two units of combining value which are taken up by one of the carbon atoms.

The equation $\text{C}_2\text{H}_4\text{O} + 2\text{FeCl}_3 + \text{H}_2\text{O} = \text{HC}_2\text{H}_3\text{O}_2 + 2\text{FeCl}_2 + 2\text{HCl}$ is explained in the same manner as the preceding equation.

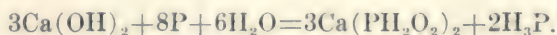
The equation $2\text{FeI}_2 + 3\text{O} + \text{H}_2\text{O} = 2\text{OFeOH} + 4\text{I}$ shows that the two iron atoms together with the four iodine atoms gain together six units of algebraic combining value while each of the three oxygen atoms changes its value from zero to -2 .

When two molecules of H_2S and one molecule of SO_2 form water and free sulphur the two sulphur atoms of the $2\text{H}_2\text{S}$ gain four units while the S of the SO_2 loses four units.

In the equation $\text{Sb}_2\text{S}_3 + 9\text{O} = \text{Sb}_2\text{O}_3 + 3\text{SO}_2$ each of the sulphur atoms changes its value from -2 to $+4$, or six units; these 18 units are lost by the oxygen.

In the reaction $6\text{KOH} + 6\text{I} = 5\text{KI} + \text{KIO}_3 + 3\text{H}_2\text{O}$ the only element changing its combining value is the iodine; but five of the iodine atoms lose five units and the sixth gains five.

The phosphorus is the only element which changes its algebraic combining number in



Six atoms of the P gain one unit each and the remaining two atoms lose those six units.

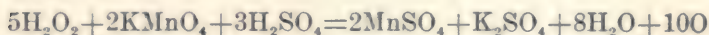
The "valence" of the sulphur atom in $(\text{HO})_2\text{SO}_2$ is 6 and that of the sulphur in H_2S is 2; the difference is 4 units. But the algebraic combining value of the S in the acid is $+6$ and that of the S in the sulphide is -2 ; the difference is then seen to be not 4 units but 8. That it is in reality 8 units and not

four may be seen from the fact that 24 units of oxidation are required to convert three molecules of H_2S into H_2SO_4 :



The compound H_2O_2 is a powerful oxidizing agent because one-half of its oxygen must have a combining value of zero. This oxygen is easily liberated and when it enters into combination with some other element its combining value changes from zero to -2 . The liberation of one-half of the oxygen of H_2O_2 is not reduction because the oxygen set free does not change its algebraic combining number.

In the reaction—



each atom of manganese changes its combining value from $+7$ to $+2$, losing 5 units; these 10 units liberate all the oxygen from the $5\text{H}_2\text{O}_2$ because one-half of that oxygen already has a combining value of zero and the other half must require just 10 units of oxidation to change it to zero. As potassium permanganate does not “give up oxygen on the addition of an acid” unless a reducing agent is present the reduction in this case is performed by one-half of the oxygen of the H_2O_2 which increases its algebraic combining value from -2 to zero. The fact that H_2O_2 in this reaction must be regarded as a reducing agent whereas it is generally an oxidizing agent seems paradoxical; but when combined oxygen having an algebraic combining value of -2 is liberated its value rises to zero, and when oxygen having a value of zero enters into combination and changes its value to -2 this change is a reduction.

The combining value of one of the carbon atoms of oxalic acid is $+4$ and that of the other is $+2$. In the reaction



five carbon atoms gain 10 units which are lost by the two manganese atoms. Compare this with the preceding example.

In the reaction



it may be readily seen that the manganese atom changes its

combining value from $+2$ to $+4$. The two units gained by it are lost by one of the oxygen atoms of the H_2O_2 . In this case, therefore, the H_2O_2 acts as an oxidizing agent, for one-half of its oxygen changes its real combining value from 0 to -2 .

145. As all uncombined elements have a combining value of 0, and have no bonds, and as all atoms in combination must have either positive or negative bonds, or both, it follows that oxidation and reduction attend all chemical reactions by which any free element enters into combination, or by which any element is liberated from a compound, except in cases where the algebraic sum of the bonds of that element is 0 when it is in combination as well as when uncombined.

In the reaction $\text{Fe} + 2\text{I} = \text{FeI}_2$ it is evident that the Fe is oxidized from a value of 0 to a value of $+2$, and that each of the two iodine atoms is reduced from 0 to -1 .

In the reaction $\text{HgO} = \text{Hg} + \text{O}$ it is evident that the Hg is reduced from a value of $+2$ to a value of 0, and the value of the oxygen atom is raised from -2 to 0.

In the reaction $\text{H}_2\text{O}_2 = \text{H}_2\text{O} + \text{O}$ it is evident that the value of one of the oxygen atoms in the molecule H_2O_2 must be 0, and its value remain 0 when it is set free.

146. The algebraic or true combining value of any atom having only positive bonds, or one having a greater number of positive bonds than of negative bonds, is a plus quantity.

The algebraic combining value of any atom having only negative bonds or one having a greater number of negative bonds than of positive bonds, is a minus quantity.

The algebraic combining value of any atom having an equal number of positive bonds and negative bonds is 0.

The algebraic combining number or true combining value of any atom in combination is the algebraic sum of its positive and its negative bonds.

147. We have elsewhere (par. 37) shown how the polarity of any atom in combination may be determined.

The combining value of any atom in combination is found from the known constant valences of atoms having bonds of exclusively negative polarity, or from positive elements known to have constant valences, or from the constant valences of compound radicals.

The elements H, Li, Na, K, Mg, Ca, Sr, Ba, B, Al, Ag, Zn and F have constant valences in combination with other elements.

Oxygen always has a combining value of -2 when in combination with any other element (not when two or more oxygen atoms are in immediate combination with each other).

Sulphur always has a valence of -2 when in combination with any other element except oxygen or a halogen (but not always when two or more sulphur atoms are in immediate combination with each other).

The halogens in combination all have a valence of -1 except when in immediate combination with oxygen or with each other.

As the algebraic sum of the units of the positive and negative bonds of any molecule must be 0 the algebraic sum of the bonds of any one element in a compound molecule must be the remainder found by deducting the algebraic sum of all the bonds of the other elements from 0; and the algebraic sum of all the bonds of all the elements but one in any compound molecule must be the remainder found by deducting the algebraic sum of the one other element from 0.

The algebraic sum of the bonds of the group CO_3 in CaCO_3 must be -2 because the sum of the bonds of the Ca is known to be $+2$. The algebraic sum of the bonds of the MnO_4 in KMnO_4 must be -1 because the K has a value of $+1$; but the algebraic sum of the bonds of the MnO_4 in K_2MnO_4 is not -1 but -2 because the sum of the bonds of the K_2 is $+2$.

The value of the Mn in KMnO_4 must be $+7$ because the algebraic sum of the bonds of K and O_4 is -7 ; and the value of the Mn in K_2MnO_4 must be $+6$ because the algebraic sum of the bonds of K_2 and O_4 is -6 .

148. Oxidation and reduction always go together. There can be no oxidation without reduction, and no reduction without oxidation. Oxidation and reduction always balance each other, unit for unit, and when the atoms oxidized or reduced are not those of uncombined elements the oxidation and reduction together constitute a **transfer** of algebraic combining value, or a transfer of bonds, or a transfer of charges of positive or negative electricity.

149. To balance equations representing reactions involving oxidation and reduction:

I. Write the factors and products in the form of an equation in the same way as in reactions not attended by changes of atomic combining value (par. 142), representing all free elements as single atoms.

II. Identify the elements which change their combining values by comparing their respective values in the factors with those in the products.

III. The total number of units of algebraic combining value transferred is a common multiple of the units lost by the oxidizing atom or atoms and the units gained by the reducing atom or atoms. Hence the **proportions** of oxidizing agents and reducing agents are found by multiplying the oxidizing agents by the units gained by the reducing agents, and the reducing agents by the units lost by the oxidizing agents.

These three steps lead to the correct **proportions** of the oxidizing agents and reducing agents in all cases, and in most cases the whole equation will then be found to balance. But in cases where it does not it will be found that the general principles applied in balancing reactions not attended by oxidation and reduction are applicable in completing the problem.

See also Chapter XV.

Additional factors and products may be found to be required besides the oxidizing and reducing agents. Water is frequently one of the additional factors or products.

All equations should be reduced to their simplest terms.

150. Any atom having a greater algebraic combining value before the reaction than after it is an oxidizing agent.

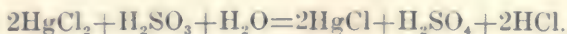
Any atom having a greater algebraic combining value after the reaction than before is a reducing agent.

151. The following examples illustrate the procedure:

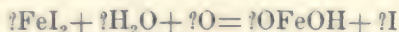


Here we find that the Hg of HgCl_2 has a combining value of +2, while the Hg of HgCl has a value of only +1. The S of H_2SO_3 has a combining value of +4, while the S of the

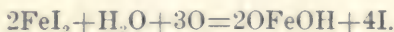
H_2SO_4 has a value of +6. No other atoms change their combining values. The Hg is the oxidizing atom and loses 1 unit; the S is the reducing atom and gains 2 units. Hence we multiply the HgCl_2 by 2 and the H_2SO_3 by 1. The equation will, therefore, stand:



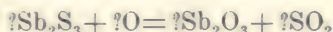
In the reaction—



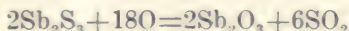
we find that the Fe changed its value from +2 to +3 and the iodine atoms change their value from -1 to zero. All of the atoms contained in the FeI_2 , therefore, gain together 3 units. The oxygen changes its value from zero to -2. The value of the H remains unchanged. Hence we get:



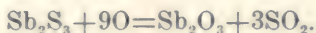
In the reaction—



we find that the S changes its value from -2 to +4 and as there are three sulphur atoms in Sb_2S_3 the S of the whole molecule gains 18 units. The O loses 2 units. Hence we write



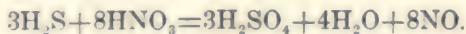
but we can reduce this equation to simpler terms by dividing all the factors and products by the common divisor 2, which will give us:



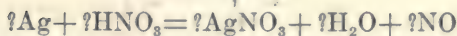
In—



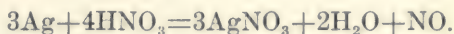
we find that the S changes its value from -2 to +6, a gain of 8 units. The N changes its value from +5 to +2, a loss of 3 units. Hence we write



In—

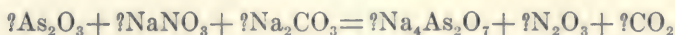


the Ag gains 1 unit while the N loses 3. Hence we require 3 Ag for each molecule of HNO_3 to **balance the oxidation and reduction**; but as each molecule of $AgNO_3$ requires an additional molecule of HNO_3 we find that the equation will be

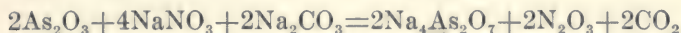


The one molecule of HNO_3 **required for the oxidation** is reduced to NO and hence can not form $AgNO_3$.

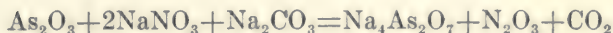
In—



the two atoms of As of the As_2O_3 gain each 2 units; the N of the $NaNO_3$ loses 2 units. Hence we write



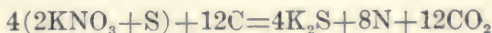
or—



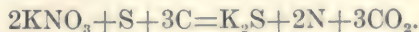
In—



we find that the N changes its value from +5 to 0 and the S from 0 to -2, while the C changes its value from 0 to +4. At the same time we see that two atoms of K and one atom of S are required to form the K_2S . Hence we get—

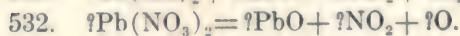
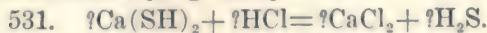


or—



EXAMPLES.

[Several of these reactions will be found **not** to be attended by any changes of combining value. They are included to test the student's judgment.]



533. $?H_4NNO_3 = ?H_2O + ?N_2O.$
534. $?H_2SO_2 = ?H_2SO_3S + ?H_2O.$
535. $?H_2SO_3 = ?H_2SO_4 + ?S + ?H_2O.$
536. $?H_2SO_3S = ?S + ?H_2O + ?SO_2.$
537. $?KCN + ?S = ?KSCN.$
538. $?HOCN + ?H_2O = ?CO_2 + ?H_3N.$
539. $?FeCl_2 + ?Zn = ?ZnCl_2 + ?Fe.$
540. $?CuSO_4 + ?Fe = ?FeSO_4 + ?Cu.$
541. $?Hg(NO_3)_2 + ?Cu = ?Cu(NO_3)_2 + ?Hg.$
542. $?KI + ?Cl = ?KCl + ?I.$
543. $?Fe_2O_3 + ?H = ?Fe + ?H_2O.$
544. $?SO_2 + ?H = ?H_2S + ?H_2O.$
545. $?KIO_3 + ?C = ?KI + ?CO.$
546. $?CaSO_4 + ?C = ?CaS + ?CO.$
547. $?CaSO_4 + ?C = ?CaS + ?CO_2.$
548. $?Na_2SO_4 + ?C = ?Na_2S + ?CO.$
549. $?H_2SO_4 + ?C = ?H_2O + ?SO_2 + ?CO_2.$
550. $?FeCl_3 + ?Fe = ?FeCl_2.$
551. $?FeCl_3 + ?Zn = ?FeCl_2 + ?ZnCl_2.$
552. $?Fe(NO_3)_3 + ?Fe = ?Fe(NO_3)_2.$
553. $?Fe_2(SO_4)_3 + ?Fe = ?FeSO_4.$
554. $?HgCl_2 + ?Fe = ?HgCl + ?FeCl_2.$
555. $?Cu + ?H_2SO_4 = ?CuSO_4 + ?H_2O + ?SO_2.$
556. $?Hg(NO_3)_2 + ?Hg = ?HgNO_3.$
557. $?Hg(NO_3)_2 + ?Hg = ?HgO + ?NO_2.$
558. $?NaHSO_3 + ?Zn = ?NaHSO_2 + ?Na_2SO_3 + ?ZnSO_3 + ?H_2O.$
559. $?Zn + ?H_2SO_3 = ?ZnSO_3 + ?H_2SO_2 + ?H_2O.$
560. $?CS_2 + ?O = ?CO_2 + ?SO_2.$
561. $?FeI_2 + ?H_2O + ?O = ?OFeOH + ?I.$
562. $?SO_2 + ?O + ?N_2O_3 + ?H_2O = ?HOSO_2ONO.$
563. $?HOSO_2ONO + ?H_2O = ?H_2SO_4 + ?N_2O_3.$
564. $?Sb_2S_3 + ?O = ?Sb_2O_3 + ?SO_2.$
565. $?H_2S + ?Cl + ?H_2O = ?H_2SO_4 + ?HCl.$
566. $?K_4Fe(CN)_6 + ?Cl = ?K_3Fe(CN)_6 + ?KCl.$
567. $?NaHSO_3 + ?I + ?H_2O = ?NaHSO_4 + ?HI.$
568. $?Na_2SO_3 + ?Na_2S + ?I = ?Na_2SO_3S + ?NaI.$
569. $?Na_2SO_3S + ?I = ?Na_2S_4O_6 + ?NaI.$
570. $? (H_4N)_2S + ?I = ?H_4NI + ?S.$
571. $?KPH_2O_2 + ?I + ?H_2O = ?KI + ?H_3PO_4 + ?HI.$

572. $?As_2O_3 + ?NaHCO_3 + ?I$
 $= ?Na_2HAsO_4 + ?NaI + ?H_2O + ?CO_2.$
573. $?KOSbC_4H_4O_6 + ?I + ?NaHCO_3$
 $= ?NaSbO_3 + ?NaI + ?KNaC_4H_4O_6.$
574. $?H_2SO_3 + ?H_2O + ?I = ?H_2SO_4 + ?HI.$
575. $?KOH + ?I = ?KI + ?KIO_3.$
576. $?Ca(OH)_2 + ?Cl = ?CaCl_2 + ?Ca(ClO_3)_2 + ?$
577. $?S_2Cl_2 + ?H_2O = ?HCl + ?SO_2 + ?S.$
578. $?Na_2SO_3 + ?S = ?Na_2SO_3S.$
579. $?Sb_2S_3 + ?Na_2S + ?S = ?Na_3SbS_4.$
580. $?Sb_2S_3 + ?Na_2S = ?Na_3SbS_3.$
581. $?NaOH + ?S = ?Na_2SO_3S + ?Na_2SS_4 + ?$
582. $?Ca(OH)_2 + ?S = ?CaSO_3S + ?CaSS_4 + ?H_2O.$
583. $?Ca(OH)_2 + ?S = ?CaSO_3S + ?CaS + ?$
584. $?CaSS_4 + ?HCl = ?CaCl_2 + ?S + ?H_2S.$
585. $?CaSS_4 + ?HCl = ?CaCl_2 + ?S + ?H_2S_2.$
586. $?CaS + ?HCl = ?CaCl_2 + ?H_2S.$
587. $?CaSO_3S + ?CaS + ?HCl = ?CaCl_2 + ?S + ?$
588. $?CaSO_3S + ?CaSS_4 + ?HCl = ?CaCl_2 + ?S + ?$
589. $?K_2CO_3 + ?S = ?K_2SS_2 + ?K_2SO_3S + ?CO_2.$
590. $?K_2SS_2 + ?K_2SO_3S + ?HCl = ?KCl + ?S + ?H_2O.$
591. $?Ca(OH)_2 + ?P + ?H_2O = ?Ca(PH_2O_2)_2 + ?H_3P.$
592. $?SCl_2 + ?H_2O = ?SO_2 + ?HCl + ?S.$
593. $?OSCl_2 + ?H_2O = ?SO_2 + ?HCl.$
594. $?OSCl_2 + ?H_2O = ?H_2SO_3 + ?HCl.$
595. $?O_2SCl_2 + ?H_2O = ?H_2SO_4 + ?HCl.$
596. $?H_4NONO_2 = ?H_2O + ?N_2O.$
597. $?H_4NONO = ?H_2O + ?N.$
598. $?P + ?HNO_3 + ?H_2O = ?H_3PO_4 + ?NO.$
599. $?As + ?HNO_3 + ?H_2O = ?H_3AsO_4 + ?NO.$
600. $?Sb + ?HNO_3 = ?Sb_2O_3 + ?H_2O + ?NO.$
601. $?HBr + ?HNO_3 = ?Br + ?H_2O + ?NO.$
602. $?H_2S + ?HNO_3 = ?H_2SO_4 + ?$
603. $?Ag + ?HNO_3 = ?AgNO_3 + ?$
604. $?Hg + ?HNO_3 = ?HgNO_3 + ?$
605. $?Hg + ?HNO_3 = ?Hg(NO_3)_2 + ?$
606. $?Zn + ?HNO_3 = ?Zn(NO_3)_2 + ?H_2O + ?NO.$
607. $?Fe + ?HNO_3 = ?Fe(NO_3)_3 + ?$
608. $?Bi + ?HNO_3 = ?Bi(NO_3)_3 + ?$

609. $?Hg + ?H_2SO_4 + ?HNO_3 = ?HgSO_4 + ?H_2O + ?NO.$
 610. $?Sb_2S_3 + ?HNO_3 = ?Sb_2O_3 + ?H_2SO_4 + ?$
 611. $?HgI + ?HNO_3 = ?Hg(NO_3)_2 + ?HIO_3 + ?H_2O + ?NO.$
 612. $?FeCl_2 + ?HNO_3 + ?HCl = ?FeCl_3 + ?$
 613. $?Fe_2HSO_5 + ?HNO_3 + ?H_2SO_4 = ?Fe_2(SO_4)_3 + ?$
 614. $?HNO_3 + ?H = ?H_3N + ?H_2O.$
 615. $?Zn + ?HNO_3 = ?Zn(NO_3)_2 + ?H_4NNO_3 + ?$
 616. $?SO_2 + ?HNO_3 = ?H_2SO_4 + ?NO_2.$
 617. $?SO_2 + ?HNO_3 + ?H_2O = ?H_2SO_4 = ?NO.$
 618. $?Sb + ?HNO_3 = ?Sb_2O_3 + ?H_2O + ?NO_2.$
 619. $?Sn + ?HNO_3 = ?H_{10}Sn_5O_{15} + ?H_2O + ?NO_2.$
 620. $?HNO_3 + ?HCl = ?H_2O + ?ONCl + ?Cl.$
 621. $?Pb + ?NaNO_3 = ?PbO + ?NaNO_2.$
 622. $?PbS + ?HNO_3 = ?PbSO_4 + ?$
 623. $?As_2O_3 + ?NaNO_3 + ?Na_2CO_3 = Na_4As_2O_7 + ?N_2O_3 + ?CO_2$
 624. $?NaNO_2 + ?KI + ?H_2SO_4$
 $= ?NaHSO_4 + ?KHSO_4 + ?I + ?H_2O + ?NO.$
 625. $?KClO_3 = ?KCl + ?$
 626. $?KClO_3 = KClO_4 + ?KCl.$
 627. $?KClO_3 + ?HCl = ?KCl + ?H_2O + ?Cl.$
 628. $?KClO_3 + ?HCl = ?KCl + ?ClO_2 + ?H_2O.$
 629. $?MnO_2 + ?KOH + ?KClO_3 = ?K_2MnO_4 + ?KCl + ?$
 630. $?MnO_2 + ?KOH + ?KClO_3 = ?KMnO_4 + ?KCl + ?$
 631. $?FeCl_3 + ?KI = ?KCl + ?FeI_2 + ?I.$
 632. $?MnO_2 + ?HCl = ?MnCl_2 + ?H_2O + ?Cl.$
 633. $?MnO_2 + ?KOH = ?K_2MnO_4 + ?Mn_2O_3 + ?$
 634. $?FeH_2SO_5 + ?MnO_2 + ?HCl$
 $= ?Fe(SO_4)_3 + ?FeCl_3 + ?MnCl_2 + ?$
 635. $?MgBr_2 + ?MnO_2 + ?H_2SO_4$
 $= ?MgSO_4 + ?MnSO_4 + ?H_2O + ?Br.$
 636. $?Cu_2I_2 + ?MnO_2 + ?H_2SO_4$
 $= ?CuSO_4 + ?MnSO_4 + ?H_2O + ?I.$
 637. $?HPH_2O_2 + ?KMnO_4 + ?H_2SO_4$
 $= ?H_3PO_4 + ?MnSO_4 + ?K_2SO_4 + ?$
 638. $?NaPH_2O_2 + ?H_2SO_4 + ?KMnO_4 = ?$
 639. $?Fe(Ph_2O_2)_2 + ?KMnO_4 + ?H_2SO_4$
 $= ?FePO_4 + ?H_3PO_4 + ?K_2SO_4 + ?MnSO_4 + ?$
 640. $?KMnO_4 + ?KOH = ?K_2MnO_4 + ?H_2O + ?O.$

641. $?H_2O_2 + ?KMnO_4 + ?H_2SO_4$
 $= ?MnSO_4 + ?K_2SO_4 + ?H_2O + ?O.$
642. $?H_2O_2 + ?MnSO_4 + ?H_4NOH$
 $= ?MnO_2 + ?(H_4N)_2SO_4 + ?H_2O.$
643. $?H_2C_2O_4 + ?KMnO_4 + ?H_2SO_4$
 $= ?K_2SO_4 + ?MnSO_4 + ?H_2O + ?CO_2.$
644. $?FeCl_2 + ?KMnO_4 + ?H_2SO_4$
 $= ?Fe_2(SO_4)_3 + ?FeCl_3 + ?KCl + ?MnSO_4 + ?$
645. $?K_2MnO_4 + ?H_2O = ?KMnO_4 + ?MnO_2 + ?KOH.$
646. $?K_2MnO_4 = ?K_2MnO_3 + ?O.$
647. $?KI + ?KMnO_4 = ?KIO_3 + ?K_2Mn_2O_5.$
648. $?FeI_2 + ?FeCl_3 = ?FeCl_2 + ?I.$
649. $?FeCl_3 + ?H_2SO_3 + ?H_2O = ?FeCl_2 + ?H_2SO_4 + ?$
650. $?Fe_2(SO_4)_3 + ?FeCl_3 + ?KI$
 $= ?FeSO_4 + ?FeCl_2 + ?K_2SO_4 + ?KCl + ?$
651. $?FeCl_3 + ?SO_2 + ?H_2O = ?H_2SO_4 + ?FeCl_2 + ?$
652. $?HgCl_2 + ?SO_2 + ? = ?HgCl + ?H_2SO_4 + ?$
653. $?HNO_3 + ?SO_2 + ? = ?H_2SO_4 + ?N_2O_3.$
654. $?AuCl_3 + ?FeH_2SO_5 = ?Fe_2(SO_4)_3 + ?Au + ?$
655. $?CuSO_4 + ?FeH_2SO_5 + ?NaI$
 $= ?Cu_2I_2 + ?Na_2SO_4 + ?Fe_2(SO_4)_3.$
656. $?HPH_2O_2 + ?CuSO_4 + ?H_2O = ?H_3PO_4 + ?H_2SO_4 + ?CuH_2.$
657. $?Hg_3(AsO_4)_2 + ?HPH_2O_2 = ?Hg + ?As + ?H_3PO_4.$
658. $?NaOCl + ?HCl = ?NaCl + ?H_2O + ?Cl.$
659. $?CuSO_4 + ?K_2SS_2 = ?CuS + ?K_2SO_4 + ?S.$
660. $?KCN + ?PbO = ?KOCN + ?Pb.$
661. $?P + ?HNO_3 + ?H_2O = ?H_3PO_3 + ?NO.$
662. $?H_3PO_3 + ?HNO_3 = ?H_3PO_4 + ?H_2O + ?NO.$
663. $?H_3PO_3 = ?H_3PO_4 + ?H_3P.$
664. $?SO_2 + ?HNO_3 + ?H_2O = ?H_2SO_4 + ?N_2O_3.$
665. $?N_2O_3 + ?SO_2 + ?H_2O + ?O = ?SO_2OHNO_2.$
666. $?SO_2OHNO_2 + ?H_2O = ?H_2SO_4 + ?N_2O_3.$
667. $?SO_2 + ?H_2O + ?HNO_3 = ?H_2SO_4 + ?H_2O + ?NO.$
668. $?FeH_2SO_5 = ?Fe_2O_3 + ?H_2S_2O_7 + ?SO_2 + ?$
669. $?Br + ?H_2S = ?HBr + ?S.$
670. $?Sb_2S_3 + ?HCl = ?SbCl_3 + ?H_2S.$
671. $?Sb_2S_3 + ?S + ?NaOH = ?Na_3SbS_4 + ?NaSbO_3 + ?$
672. $?Na_2SbS_4 + ?H_2SO_4 = ?Sb_2S_5 + ?Na_2SO_4 + ?$
673. $?NaCl + ?H_2SO_4 + ?MnO_2 = ?Na_2SO_4 + ?MnSO_4 + ?Cl.$

674. $?K_2Cr_2O_7 + ?H_2SO_4 + ?C = ?KCr(SO_4)_2 + ?H_2O + ?CO_2.$
675. $?K_2Cr_2O_7 + ?H_2SO_4 = ?CrO_3 + ?KHSO_4 + ?$
676. $?Cu(NO_3)_2 = ?CuO + ?N_2O_4 + ?O.$
677. $?Cu + ?H_2SO_4 + ?HNO_3 = ?CuSO_4 + ?$
678. $?AuCl_3 + ?H_2C_2O_4 = ?Au + ?HCl + ?CO_2.$
679. $?Fe_2O_3 + ?C = ?Fe + ?CO_2.$
680. $?Fe_2O_3 + ?H = ?Fe + ?H_2O.$
681. $?FeCl_3 + ?C_2H_5OH = ?Fe(OH)_3 + ?C_2H_5Cl.$
682. $?FeCl_3 + ?C_2H_5OH = ?FeCl_2 + ?C_2H_4O + ?HCl.$
683. $?FeCl_3 + ?C_2H_4O + ?H_2O = ?FeCl_2 + ?HC_2H_3O_2 + ?HCl.$
684. $?FeC_2O_4 + ?O = ?Fe_2O_3 + ?CO_2.$
685. $?FeH_2SO_5 + ?H_2SO_4 + ?HNO_3 = ?Fe_4O(SO_4)_5 + ?$
686. $?FeH_2SO_5 + ?H_2SO_4 + ?HNO_3 = ?Fe_2(SO_4)_3 + ?$
687. $?Pb(NO_3)_2 + ?K_2Cr_2O_7 + ?H_2O$
 $= ?PbCrO_4 + ?KNO_3 + ?HNO_3.$
688. $?Pb(NO_3)_2 + ?Ca(ClO)_2 + ?$
 $= ?PbO_2 + ?CaCl_2 + ?Ca(NO_3)_2 + ?HCl + ?O.$
689. $?MnO_2 + ?H_2SO_4 = ?MnSO_4 + ?$
690. $?Hg_2SO_4 + ?MnO_2 + ?NaCl = ?Na_2SO_4 + ?HgO + ?MnCl_2.$
691. $?HgCl_2 + ?H_3N + ?H_2O = ?H_4NCl + ?H_2NHgCl + ?H_2O.$
692. $?HgNO_3 = ?HgO + ?$
693. $?Hg + ?H_2SO_4 + ?HNO_3 = ?HgSO_4 + ?H_2O + ?N_2O_3.$
694. $?KOH + ?S = ?K_2S + ?K_2SO_4 + ?$
695. $?KOH + ?Cl = ?KCl + ?KClO + ?$
696. $?KClO = ?KClO_3 + ?KCl.$
697. $?Ca(OH)_2 + ?Cl + ?KCl = ?CaCl_2 + ?KClO_3 + ?H_2O.$
698. $?Ca(OH)_2 + ?Cl = ?Ca(ClO_3)_2 + ?CaCl_2 + ?H_2O.$
699. $?K_4Fe(CN)_6 + ?K_2CO_3 = ?KCN + ?KOCN + ?Fe + ?CO_2.$
700. $?(Cr_2O_3 + FeO) + ?O + ?K_2CO_3$
 $= ?K_2CrO_4 + ?Fe_2O_3 + ?CO_2.$
701. $?Cr_2FeO_4 + ?Ca(OH)_2 + ?O = ?CaCrO_4 + ?Fe_2O_3 + ?H_2O.$
702. $?K_2Cr_2O_7 + ?K_2CO_3 = ?K_2CrO_4 + ?CO_2.$
703. $?K_4Fe(CN)_6 + ?PbO_2 + ?CO_2 + ?H_2O$
 $= ?KHCO_3 + ?PbO + ?K_3Fe(CN)_6.$
704. $?K_2CO_3 + ?S = ?K_2SO_3S + ?K_2SS_2 + ?CO_2.$
705. $?K_2CO_3 + ?S = ?K_2SS_2 + ?K_2SO_4 + ?CO_2.$
706. $?CuSO_4 + ?K_2SS_2 = ?CuS + ?K_2SO_4 + ?S.$
707. $?KIO_3 + ?C = ?KI + ?CO_2.$
708. $?PI_3 + ?H_2O = ?H_3PO_3 + ?HI.$

709. $?PI_5 + ?H_2O = ?H_3PO_4 + ?HI$.
710. $?H_3PO_3 + ?I + ?H_2O = ?H_3PO_4 + ?HI$.
711. $?(6NaF + 2AlF_3) + ?CaCO_3 = ?Na_3AlO_3 + ?CaF_2 + ?CO_2$
712. $?Na_3AlO_3 + ?CO_2 + ?H_2O = ?Na_2CO_3 + ?Al(OH)_3$.
713. $?NaCl + ?H_3N + ?CO_2 + ?H_2O$
 $= ?H_4NHCO_3 + ?NaHCO_3 + ?H_4NCl$.
714. $?NaHCO_3 = ?Na_2CO_3 + ?H_2O + ?CO_2$.
715. $?C_2H_5OH + ?Na = ?NaOC_2H_5 + ?H$.
716. $?Ca(OC_2H_5)_2 + ?CaCl_2 + ?Na_2CO_3$
 $= ?NaOCl + ?NaCl + ?CaCO_3$.
717. $?NaOH + ?S + ?SO_2 = ?Na_2SO_3S + ?$
718. $?CaSS_4 + ?HCl = ?CaCl_2 + ?Ca(SH)_2 + ?S$.
719. $?CaSS_4 + ?CaSO_3S + ?HCl = ?CaCl_2 + ?S + ?$
720. $?Ca_3(AsS_4)_2 + ?HCl = ?As_2S_3 + ?CaCl_2 + ?S + ?H_2S$.
721. $?Ca(SH)_2 + ?HCl = ?CaCl_2 + ?H_2S$.
722. $?CaSS_4 + ?CaSO_3S + ?HCl = ?CaCl_2 + ?S + ?H_2O + ?H_2S_2$.
723. $?H_4C + ?Cl = ?H_3CCl + ?HCl$.
724. $?H_4C + ?Cl = ?H_2CCl_2 + ?HCl$.
725. $?H_4C + ?Cl = ?HCCl_3 + ?HCl$.
726. $?H_4C + ?Cl = ?CCl_4 + ?HCl$.
727. $?C_2H_5OH + ?O = ?C_2H_4O + ?H_2O$.
728. $?C_2H_4O + ?O = ?HC_2H_3O_2$.
729. $?C_2H_5OH + ?Cl = ?C_2H_4O + ?HCl$.
730. $?C_2H_4O + ?Cl = ?C_2HCl_3O + ?HCl$.
731. $?C_2H_5OH + ?FeCl_3 = ?FeCl_2 + ?C_2H_4O + ?HCl$.
732. $?C_2H_5OH + ?FeCl_3 = ?FeCl_2 + ?C_2H_4O + ?C_2H_5Cl + ?$
733. $?C_{12}H_{22}O_{11} + ?HNO_3 = ?H_2O + ?NO + ?CO_2$.
734. $?C_6H_{10}O_5 + ?HNO_3 = ?C_6H_8(NO_3)_2O_3 + ?H_2O$.
735. $?C_6H_7(NO_3)_3O_2 + ?FeH_2SO_5 + ?HCl$
 $= ?C_6H_{10}O_5 + ?Fe_2(SO_4)_3 + ?FeCl_3 + ?H_2O + ?NO$.
736. $?C_3H_5(OH)_3 + ?HNO_3 = ?H_2O + ?NO + ?CO_2$.
737. $?C_2H_5OH + ?K_2CrO_4 + ?H_2SO_4$
 $= ?HC_2H_3O_2 + ?KCr(SO_4)_2 + ?K_2SO_4 + ?H_2O$.
738. $?KC_2H_3O_2 + ?O = ?K_2CO_3 + ?H_2O + ?CO_2$.
739. $?NaC_7H_5O_2 + ?O = ?Na_2CO_3 + ?H_2O + ?CO_2$.
740. $?KHC_4H_4O_6 + ?O = ?K_2CO_3 + ?$
741. $?KNaC_4H_4O_6 + ?O = ?KNaCO_3 + ?$
742. $?K_3C_6H_5O_7 + ?O = ?K_2CO_3 + ?$
743. $?Sr(C_3H_5O_3)_2 + ?O = ?SrCO_3 + ?$

744. $?Pb(NO_3)_2 + ?KOH + ?Al = ?Pb + ?KAlO_2 + ?H_3N.$
 745. $?Ag_3AsO_4 + ?KOH + ?Al$
 $= ?Ag + ?KAlO_2 + ?H_2O + ?H_3As.$
 746. $?Na_2SO_3S + ?I = ?Na_2S_4O_6 + ?NaI.$
 747. $?H_2S_4O_6 = ?H_2SO_4 + ?SO_2 + ?S.$
 748. $?(H_4N)_2S + ?I = ?H_4NI + ?S.$
 749. $?As_2O_3 + ?NaHCO_3 + ?I$
 $= ?Na_2HAsO_4 + ?NaI + ?H_2O + ?CO_2.$
 750. $?Fe(OH)_2 + ?HClO_3 = ?FeCl_3 + ?Fe(ClO_3)_3 + ?$
 751. $?Fe_3(AsO_3)_2 + ?HClO_3$
 $= ?FeCl_3 + ?Fe(ClO_3)_3 + ?H_3AsO_4 + ?$
 752. $?KO.CO.NH_2 + ?H_2O = ?H_3N + ?KHCO_3.$
 753. $?OCCl_2 + ?H_3N = ?OC(NH_2)_2 + ?HCl.$
 754. $?OC(NH_2)_2 + ?HNO_2 = ?CO_2 + ?N + ?H_2O.$
 755. $?H_4NO.CO.NH_2 = ?OC(NH_2)_2 + ?H_2O.$
 756. $?KClO_3 + ?H_2SO_4 = ?KClO_4 + ?ClO_2 + ?K_2SO_4 + ?$
 757. $?Na_2SO_3S + ?H_2SO_4 = ?Na_2SO_4 + ?S + ?SO_2 + ?H_2O.$
 758. $?Pb(NO_3)_2 + ?Ca(ClO)_2 + ?H_2O$
 $= ?PbO_2 + ?Ca(NO_3)_2 + ?HCl + O.$
 759. $?Pb(NO_3)_2 + ?Ca(ClO)_2 + ?H_2O$
 $= ?PbO_2 + ?CaCl_2 + ?Ca(NO_3)_2 + ?HCl + 3O.$
 760. $?Pb(NO_3)_2 + ?Ca(ClO)_2 + ?H_2O$
 $= ?PbO + ?CaCl_2 + ?Ca(NO_3)_2 + ?HCl + 4O.$
 761. $?Ca(OH)_2 + ?S = ?CaSO_3S + ?CaS + ?$
 762. $?SC(SH)_2 = ?CS_2 + ?H_2S.$
 763. $?S_2O_7 = ?SO_3 + ?O.$
 764. $?H_2SO_4 = ?H_2S_2O_8 + ?H.$
 765. $?K_2S_2O_8 + ?H_2O = ?KHSO_4 + ?H_2O_2.$
 766. $?Na + ?H_3N = ?NaNH_2 + ?H.$
 767. $?NaNNH_2 + ?N_2O = ?NaN_3 + ?H_2O.$
 768. $?NaN_3 + ?H_2SO_4 = ?Na_2SO_4 + ?HN_3.$
 769. $?H_3N + ?HIN_3 = ?H_4NN_3.$
 770. $H_5N_3 = H_4N_2 + HN_3.$
 771. $H_3Cl + KCN = H_3CCN + KI.$
 772. $H_3Cl + AgCN = H_3CNC + AgI.$
 773. $H_3N + 3Cl = 3HCl + N.$
 774. $P_2S_5 + 6H_2O = 2H_3PO_3 + 3H_2S.$
 775. $P_2S_5 + 8H_2O = 2H_3PO_4 + 5H_2S.$
 776. $2BiCl_3 + 2H = Bi_2Cl_4 + 2HCl.$

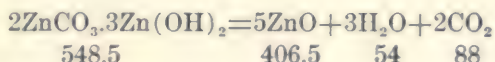
777. $\text{Zn}_3\text{As}_2 + 3\text{H}_2\text{SO}_4 = 3\text{ZnSO}_4 + 2\text{H}_3\text{As}.$
 778. $\text{SO}_3 + \text{PCl}_3 = \text{OPCl}_3 + \text{SO}_2.$
 779. $\text{BN} + 3\text{H}_2\text{O} = \text{B}(\text{OH})_3 + \text{H}_3\text{N}.$
 780. $\text{CaSO}_4 + 3\text{C} = \text{CaS} + 2\text{CO} + \text{CO}_2.$
 781. $? \text{AgNO}_3 + ? \text{H} = ? \text{H}_4\text{NNO}_3 + ? \text{Ag} + ? \text{H}_2\text{O}.$
 782. $? \text{AsFeS} + ? \text{O} = ? \text{Fe}_2\text{O}_3 + ? \text{SO}_2 + ? \text{As}_2\text{O}_3.$
 783. $50\text{SbCl} = \text{Sb}_4\text{O}_5\text{Cl}_2 + \text{SbCl}_3.$
 784. $8\text{Cu} + \text{As}_2\text{O}_3 + 6\text{HCl} = \text{Cu}_5\text{As}_2 + 3\text{CuCl}_2 + 3\text{H}_2\text{O}.$
 785. $? \text{SnCl}_2 + ? \text{HgCl}_2 = ? \text{HgCl} + ? \text{SnCl}_4.$
 786. $? \text{Cr}_2\text{O}_3 + ? \text{NaNO}_3 + ? \text{Na}_2\text{CO}_3 = ? \text{Na}_2\text{CrO}_4 + ? \text{CO}_2 + ? \text{NO}.$
 787. $? \text{K}_2\text{Cr}_2\text{O}_7 + ? \text{H}_2\text{S} + ? \text{H}_2\text{SO}_4 = ? \text{KCr}(\text{SO}_4)_2 + ? \text{S} + ? \text{H}_2\text{O}.$
 788. $? \text{FeCl}_3 + ? \text{H}_2\text{S} = ? \text{FeCl}_2 + ? \text{HCl} + ? \text{S}.$
 789. $? \text{H}_3\text{N} + ? \text{O} + ? \text{K}_2\text{CO}_3 = ? \text{KNO}_3 + ? \text{H}_2\text{O} + ? \text{CO}_2.$
 790. $? \text{ZnS} + ? \text{HCl} = ?$
 791. $? \text{AgNO}_3 + ? \text{H}_3\text{Sb} = ? \text{Ag}_3\text{Sb} + ? \text{HNO}_3.$
 792. $? \text{KCr}(\text{SO}_4)_2 + ? (\text{H}_4\text{N})_2\text{S} + ? \text{H}_2\text{O}$
 $= ? \text{Cr}(\text{OH})_3 + ? \text{K}_2\text{SO}_4 + ? (\text{H}_4\text{N})_2\text{SO}_4 + ? \text{H}_2\text{S}.$
 793. $? \text{ZnCl}_2 + ? \text{H}_2\text{S} + ? \text{NaC}_2\text{H}_3\text{O}_2 = ? \text{ZnS} + ? \text{NaCl} + ? \text{HC}_2\text{H}_3\text{O}_2.$
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CHAPTER XIV.

EXAMPLES IN STÖECHIOMETRY.

In these practice problems it is intended that the atomic and molecular weights employed shall be the approximately correct "rounded off" numbers.

1. What quantity of zinc oxide can be obtained from 1 kilo of zinc carbonate?

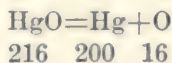


Hence—

$$548.5 : 1000 :: 406.5 : 742.$$

Answer: 742 Gm.

2. How much mercury is contained in 100 Gm of mercuric oxide?

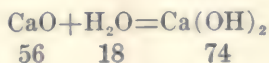


Hence—

$$\text{X} : 100 :: 200 : 216.$$

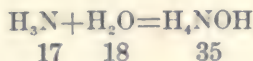
Answer: 92.6 Gm.

3. How much calcium hydroxide can be made out of 240 Gm of CaO?



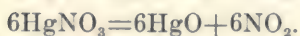
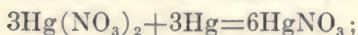
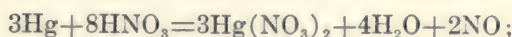
Answer: 317.14 Gm.

4. The common ammonia water contains 10% of H_3N . What per cent. of H_4NOH does it contain?

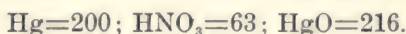


Answer: 20.59%.

5. How much nitric acid of 68% strength will be required to make red oxide of mercury out of 2 kilos of mercury?



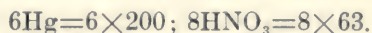
Hence 6 atoms of Hg require 8 molecules of absolute (100%) nitric acid to make 6 molecules of HgO.



Answer: 1260 Gm.

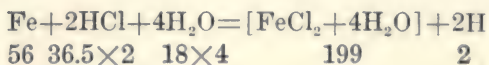
6. How much nitric acid of 63% strength must be used to make HgO out of 1200 Gm of mercury?

From the equations set down in the preceding example it is seen that 6 atoms of mercury require 8 molecules of nitric acid of 100% strength to make six molecules of HgNO_3 out of which we can make 6 molecules of HgO.



Hence 1200 Gm of mercury will require 800 Gm of HNO_3 of 63% strength.

7. How much $\text{FeCl}_2 + 4\text{H}_2\text{O}$ can be produced by saturating 1,000 Gm of a 32% solution of hydrogen chloride?



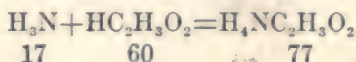
Answer: 872.34 Gm.

8. How much $\text{FeCl}_2 + 4\text{H}_2\text{O}$ can be produced by saturating 1000 Gm of a 36.4% solution of HCl?

As 199 Gm of $\text{FeCl}_2 + 4\text{H}_2\text{O}$ will require 73 Gm of HCl of 100% strength (or 1 molecule of ferrous chloride will require 2 molecules of hydrogen chloride) it follows that 200 Gm of a 36.4% solution of HCl will make 199 Gm of the crystallized ferrous chloride.

Answer: 995 Gm.

9. Wanted: 1000 Gm of a water-solution containing 10% of $\text{H}_4\text{NC}_2\text{H}_3\text{O}_2$. How much ammonia water of 28% H_3N and acetic acid of 36% will be required to make it? And how much additional water must be used?

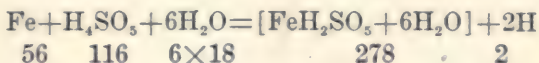


Answer: 78.8 Gm of 28% solution of H_3N , 216.2 Gm of acetic acid of 36% strength, and 705 Gm of water.

10. How much ammonia solution containing 17% of H_3N , hydrogen acetate solution containing 60% of $\text{HC}_2\text{H}_3\text{O}_2$, and how much water will be required to make 1000 Gm of a 7.7% solution ammonium acetate?

Answer: 100 Gm of the ammonia solution; 100 Gm of the acetic acid; and 800 Gm of water.

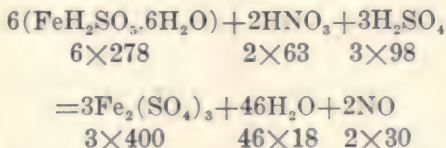
11. How much $\text{FeH}_2\text{SO}_5 + 6\text{H}_2\text{O}$ will be contained in a solution made by saturating 1160 Gm of absolute monometasulphuric acid (H_4SO_5) in sufficient water?



Answer: 2780 Gm.

12. How much $\text{FeH}_2\text{SO}_5 + 6\text{H}_2\text{O}$, sulphuric acid containing 92.5% of H_2SO_4 , nitric acid containing 68% of HNO_3 , and water, will be required to make 1000 Gm of a solution containing 28.7% of $\text{Fe}_2(\text{SO}_4)_3$?

The equation is:



Thus we shall require 1668 Gm of ferrous sulphate, 294 Gm of absolute H_2SO_4 , and 126 Gm of absolute HNO_3 to make 1200 Gm of $\text{Fe}_2(\text{SO}_4)_3$ and these quantities of the factors will pro-

duce also 828 Gm of water. As the quantity required of $\text{Fe}_2(\text{SO}_4)_3$ is 287 Gm, we have—

$$1200 : 287 :: \left\{ \begin{array}{l} 1668 : X = 398.93 \text{ Gm ferrous sulphate.} \\ 294 : X = 70.31 \text{ Gm H}_2\text{SO}_4. \\ 126 : X = 30.13 \text{ Gm HNO}_3. \end{array} \right.$$

But 70.31 Gm of absolute H_2SO_4 is $70.31 \times \frac{100}{92.5}$ Gm of 92.5% sulphuric acid, and 30.13 Gm of absolute HNO_3 is $30.13 \times \frac{100}{68}$ Gm of 68% nitric acid. Hence, to make 1000 Gm of a 28.7% solution of $\text{Fe}_2(\text{SO}_4)_3$ we shall have to use:

398.93 Gm ferrous sulphate
 76.01 Gm sulphuric acid of 92.5%
 44.31 Gm nitric acid of 68%
 480.75 Gm water

1000.00 Gm, containing 287 Gm of $\text{Fe}_2(\text{SO}_4)_3$.

13. How much $\text{FeH}_2\text{SO}_5 \cdot 6\text{H}_2\text{O}$, sulphuric acid containing 98% of H_2SO_4 , nitric acid containing 63% of HNO_3 , and water, will be required to make 1000 Gm of a solution containing 40% of $\text{Fe}_2(\text{SO}_4)_3$?

From the chemical equation given in the preceding example we found that 1668 Gm of ferrous sulphate (6 molecules), 294 Gm of H_2SO_4 (3 molecules), and 126 Gm of HNO_3 (2 molecules) are required to make 1200 Gm (3 molecules) of $\text{Fe}_2(\text{SO}_4)_3$. We want only one-third as much. Hence—

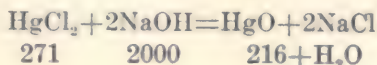
Answer: 556.00 Gm ferrous sulphate
 100.00 Gm 98% sulphuric acid
 66.67 Gm 63% nitric acid
 277.33 Gm water

to make 1000.00 Gm of solution containing 400 Gm of $\text{Fe}_2(\text{SO}_4)_3$.

Stoichiometric problems, as will be seen from this example, are more expeditiously solved when the solutions used (acids, etc.) are of percentage strengths bearing simple relations to the molecular weights of the respective factors and products. Thus, as the mol. w. of H_2SO_4 is 98, it follows that 100 weight units of a 98% acid will be required for each molecule called

for by the equation; 100 parts of nitric acid will be required for each molecule if the strength of the acid be 63%, because the mol. w. is 63; and 1000 parts of finished 40% solution of ferric sulphate will be obtained for each molecule of that salt produced according to the equation.

14. The mol. w. of HgO is 216; that of NaOH is 40; and that of HgCl₂ is 271. What quantities are required of the mercuric chloride and of a 4% solution of NaOH to produce 500 Gm of HgO?



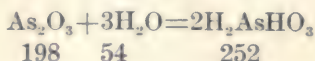
Therefore,

$$216 : 500 \quad \left\{ \begin{array}{l} 271 : X = 627 \text{ Gm of HgCl}_2. \\ 2000 : X = 4630 \text{ Gm of the solution.} \end{array} \right.$$

15. What amount of 4% solution of NaOH is required to make HgO out of 5 parts of HgCl₂?

Answer: 39 parts.

16. How much arsenous acid is contained in a solution made of 198 Gm As₂O₃ and 20 liters of water?



Answer: 252 Gm.

EXAMPLES.

794. How much solution containing 36.5% of HCl is required to form the ferrous chloride necessary to make 1000 Gm of a solution containing 32.5% of FeCl₃ (or 54.1% of FeCl₃·6H₂O)?

795. How much hydrogen chloride solution of 36.5% strength will be required to transform the FeCl₂ in the preceding problem into FeCl₃? And how much hydrogen nitrate solution of 63% strength?

796. How much solution of Fe₂(SO₄)₃ of 40% strength, ammonia water containing 35% of H₄NOH, and hydrogen chloride solution of 36.5% strength will be required for 2 kilos of a 16.25% solution of FeCl₃?

Mol. w. of $\text{Fe}_2(\text{SO}_4)_3=400$; mol. w. of $\text{H}_4\text{NOH}=35$; mol. w. of $\text{HCl}=36.5$; mol. w. of $\text{Fe}(\text{OH})_3=107$; and of $\text{FeCl}_3=162.5$.

797. How much solution of KOH of 5% strength is equivalent to 5.6 Gm of KOH the mol. w. of which is 56?

798. The mol. w. of NaOH is 40. What quantity of 5% solution contains 40 Gm?

799. How much "hydrochloric acid" of 31.9% strength equals 1 kilo of solution containing 36.5% of absolute HCl?

800. By what number must 1 weight unit of hydrochloric acid of 31.9% strength be multiplied to find the corresponding quantity of an acid of 36.5%?

801. By what number must 2 kilos of hydrochloric acid of 36.5% strength be multiplied to find the corresponding quantity of an acid of 31.9% strength?

802. By what co-efficient must any number of grams of nitric acid of 63% strength be multiplied to find the corresponding number of grams of an acid of 68% strength?

803. The strength of your acetic acid being 36% and the mol. w. of absolute acid 60, how much of your acid will contain 60 Gm? By what number must any quantity of the 36% acid be multiplied to find the corresponding quantity of an acid of 60%?

804. A working-formula in the Pharmacopœia calls for a certain quantity of sulphuric acid of 92.5% strength. The acid you have contains 95%. How much acid of 95% must you use for each 100 Gm of acid of 92.5%?

805. By what number must any number of grams of sulphuric acid of 100% strength be multiplied to find the corresponding number of grams of acid of 92.5% strength? Of 98% strength? Of 93%? Of 96%?

806. How many times is 1.0594 contained in 1? And how many times is 0.9439 contained in 1? What is the reciprocal of 1.0594? And of 0.9439?

807. By what co-efficient must any number of grams of sulphuric acid of 92.5% strength be multiplied to find the corresponding quantity of absolute H_2SO_4 ?

808. Having found what quantity of acid of 100% strength is required, how would you find the corresponding quantity of acid of any other strength?

809. I want to turn 280 Gms of $\text{HgNO}_3 \cdot \text{H}_2\text{O}$ into red oxide of mercury by heating it. How much product will I get?

810. By what number must I multiply any quantity of $\text{HgNO}_3 \cdot \text{H}_2\text{O}$ to find the quantity of HgO which it will produce?

811. Ferric acetate is $\text{Fe}(\text{C}_2\text{H}_3\text{O}_2)_3$. What fraction of it is iron?

812. How much HgCl_2 and NaOH must I have to make 100 Gm of HgI_2 ?

813. If a certain solution is guaranteed to contain 50% of Fe_2Cl_6 , how much FeCl_3 is contained in it?

814. Crystallized ferric chloride is $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$. We have a water-solution of it containing 200 Gm of that substance. To what weight must that solution be evaporated in order to form a solid mass on cooling?

815. What is the theoretical yield of H_3N from 1 kilo of H_4NCl ?

816. Magnesium carbonate is $\text{Mg}_5(\text{HO})_2(\text{CO}_3)_4$. Magnesia is MgO . How much magnesia can be made of 1 kilo of the carbonate? How much carbonate is required to make 1 kilo of the oxide?

817. Zinc carbonate is $\text{Zn}_5(\text{HO})_6(\text{CO}_3)_2$. The acetate of zinc is $\text{Zn}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot 2\text{H}_2\text{O}$. How much zinc acetate can be made from 100 Gm of the carbonate? From 100 Gm of the oxide?

818. Ammonium carbonate has the composition



How much ammonium acetate can be made out of 3 kilos of acetic acid of 60% strength by neutralizing it with ammonium carbonate? How much of the carbonate will be required?

819. We have some sodium carbonate of which 900 Gm neutralizes 4000 Gm of acetic acid of 36% strength. How much water does the carbonate contain? Give the answer in %.

820. We make ferric hydroxide from 2 kilos of solution containing 28.7% of $\text{Fe}_2(\text{SO}_4)_3$, and after washing it express the water from it until the weight of the mass is reduced to 1400 Gm. How much real $\text{Fe}(\text{OH})_3$ is contained in that 1400 Gm, and how much water? And how much Fe ?

821. How much CO_2 by weight and by volume can be made from 10 kilos of chalk? And how much water at 0° can be saturated with that CO_2 under a pressure of six atmospheres?

822. How much HCl will be required to make enough chlorine to saturate one liter of water, and how much MnCl_2 will be produced from the MnO_2 employed?

823. How much oxygen by weight and by volume is liberated from 100 Gm of a 3% solution of H_2O_2 when the dioxide is completely reduced to monoxide?

824. How much sulphurous acid in a solution of SO_2 containing 6.4% of the dioxide?

825. How much K_2CO_3 can be obtained from 100 Gm of KHCO_3 ?

826. What quantities of cupric sulphate and lead nitrate are required to make 1 kilo of cupric nitrate?

827. How many grams of $\text{Fe}(\text{OH})_3$ will be obtained from 1 kilo of a 63% solution of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ by complete precipitation with H_4NOH ?

828. What per cent of iron is contained in a 10% solution of $\text{Fe}(\text{NO}_3)_3$?

829. How much ferric hydroxide corresponds to 56 Gm of iron?

830. What amount of $\text{Fe}(\text{C}_2\text{H}_3\text{O}_2)_3$ is contained in 4 kilos of a solution of that compound if the strength of the solution corresponds to 5% of metallic iron?

831. What is the % of Fe in a solution containing 32.5% of FeCl_3 ?

832. What is the % of Fe in a solution containing 20% of $\text{Fe}_2(\text{SO}_4)_3$?

833. What per cent. of Fe is contained in a mixture of 100 ml of solution of ferric chloride having the sp. gr. 1.387 and containing 63% of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ and 300 ml of alcohol of the sp. gr. 0.820?

834. What is the percentage of As in a solution the arsenical strength of which is—

- a. 1% of Na_2HAsO_4 ?
- b. 1% of $\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$?
- c. 1% of AsI_3 ?
- d. 1.677% of $\text{Na}_2\text{HAsO}_4 \cdot 7\text{H}_2\text{O}$?
- e. 1% of As_2O_3 ?

835. How much CrO_3 can be made from $\text{K}_2\text{Cr}_2\text{O}_7$, and how much sulphuric acid will be required for the reaction?

836. What quantity of arsenous acid will be obtained from 100 Gm arsenous oxide?

837. How much calcium hydroxide will be obtained from 112 Gm calcium oxide?

838. How much magnesia will be obtained from 1 pound magnesium carbonate?

839. What amount of zinc oxide can be obtained from 1 pound zinc carbonate?

840. What amount of nitric acid of 63 per cent. strength is required to make red oxide of mercury out of 1 kilogram of mercury?

841. What amount of corrosive sublimate will be required to make 1 pound yellow oxide of mercury?

842. How much potassium hydroxide can be made from 500 Gm potassium bicarbonate?

843. What is the per cent. of ammonium hydroxide contained in the official water of ammonia?

844. How much ammonia will be obtained from 1 kilogram ammonium chloride?

845. What amount of iron is contained in the ferric hydroxide produced from 500 Gm of official solution of ferric sulphate?

846. How much ferric hydroxide can be made of 1 kilogram solution of ferric chloride U. S. P.?

847. What quantity of official hydrochloric acid is required to make 100 Gm ferrous chloride?

848. What proportions of lithium carbonate and hydrochloric acid are necessary to make 100 Gm lithium chloride?

849. What quantity of zinc chloride will be obtained by saturating 500 Gm hydrochloric acid, and how much zinc will be consumed?

850. What percentage of crystallized ferric chloride can be obtained from the official solution of chloride of iron?

851. What is the quantity of metallic iron contained in 1 Gm of the official solution of ferric chloride?

852. What amount of official nitric acid, and how much hydrochloric acid is necessary to raise 100 Gm crystallized ferrous chloride to ferric chloride?

853. How much mercury is required to make a pound of calomel?

854. How much bromide of potassium would be obtained by saturating 100 Gm official hydrobromic acid with potassium carbonate?

855. How much bromide of potassium can be made of 1 kilogram of bromine?

856. What is the difference in percentage of bromine between hydrobromic acid, potassium bromide, and lithium bromide?

857. What is the percentage of combined iodine in the official syrup of hydriodic acid?

858. What proportions of sulphur and iodine are required to make S_2I_2 ?

859. How much iodine is required to make 1 kilogram potassium iodide?

860. What quantity of combined iodine is contained in 1 Gm syrup of iodide of iron?

861. How much mercurous iodide can be made of 100 Gm mercuric iodide, and how much more mercury must be added?

862. How much mercuric iodide can be made from 1 pound mercuric chloride?

863. What proportions of arsenic and iodine are contained in AsI_3 ?

864. What quantity of hydrocyanic acid is obtained from 10 Gm silver cyanide when decomposed with hydrochloric acid?

865. What quantity of hydrocyanic acid will be obtained from 1 Gm potassium cyanide?

866. How much lead nitrate is obtained from 100 Gm lead oxide?

867. How much silver nitrate is obtained from 100 Gm silver?

868. How much bismuth is necessary for the preparation of 1 pound of the sub-nitrate?

869. What is the difference in percentage of bismuth, between the sub-nitrate and the sub-carbonate?

870. How much crystallized zinc sulphate can be obtained from 1 pound sulphuric acid containing 96 per cent. H_2SO_4 , and how much zinc will be consumed?

871. What is the percentage of zinc in the official zinc sulphate, and what percentage in a zinc sulphate containing 5 molecules of water?

872. How much ferric sulphate is obtained from 1 pound of ferrous sulphate?

873. If the citrate of iron be made from ferric hydroxide obtained from ferric sulphate, how much ferrous sulphate will be necessary to make the ferric hydroxide required for the production of 1 pound citrate of iron?

874. How much ammonia water of 10 per cent. strength is necessary to precipitate the ferric hydroxide from 1 pound of the solution of ferric sulphate?

875. How much SO_2 can be obtained from each 100 Gm of official sulphuric acid by heating with charcoal?

876. How much phosphate of sodium can be made from a kilogram of bone ash, and how much sodium carbonate will be required?

877. What is the percentage of iron in soluble phosphate of iron?

878. What is the percentage of iron in soluble pyrophosphate of iron?

879. How much potassium carbonate equals 100 Gm of potassium bicarbonate in neutralizing power?

880. How much sodium bicarbonate equals 100 Gm sodium carbonate in neutralizing power?

881. How much magnesium carbonate equals 100 Gm magnesia in neutralizing power?

882. What percentage boric acid is obtained from 100 Gm borax by decomposition with hydrochloric acid?

883. What quantity of dried sodium arsenate can be made from 100 Gm arsenous oxide?

884. What is the percentage of lead in the official solution of sub-acetate of lead and the percentage of lead in crystallized lead acetate?

885. How much Rochelle salt can be made out of a pound of cream of tartar?

886. What is the difference in percentage of bismuth between citrate of bismuth, and citrate of bismuth and ammonium?

887. What quantities of sodium bicarbonate and salicylic acid are necessary to make 1 pound of a 50 per cent. solution of sodium salicylate?

888. How much oxygen is contained in one pound mercuric oxide?

889. How much oxygen, by weight, can be obtained by heating 100 Gm KClO_3 ? How much will that oxygen measure at 15°C ? What is the residue?

890. What amount of hydrogen, by weight, can be obtained from 32 troy-ounces of water?

891. How much hydrogen gas, by weight, will be obtained from 1 kilogram diluted sulphuric acid by means of zinc? And how much Zn is consumed in decomposing that amount of the acid?

892. How much manganese di-oxide is consumed in generating 100 Gm chlorine gas with HCl? And how much official hydrochloric acid?

893. What is the weight of the chlorine gas absorbed by one liter of water, if the water takes up 1.75 volumes?

894. How much HCl can be obtained from 100 ounces of NaCl, and how much H_2SO_4 is required to decompose the salt? And how much sodium sulphate, counted as anhydrous acid salt, remains?

895. How much diluted (U. S. P.) sulphuric acid can be made from one liter concentrated sulphuric acid of 1.835 sp. w.?

896. How much official acetic acid can be obtained from 1 pound of sugar of lead? How much sulphuric acid is required to decompose that amount of the sugar of lead, and what will be the weight of the lead sulphate?

897. How much potassium citrate can be made from 50 Gm citric acid, and how much potassium bicarbonate is required for it?

898. How much lithium carbonate is required to neutralize one drachm salicylic acid?

899. How much silver chloride will be obtained from 10 Gm official hydrochloric acid by precipitation with silver nitrate?

900. How much ferrous chloride could be made from the amount of iron contained in one pound solution of ferric chloride?

901. How much normal ammonium acetate is contained in a solution made from 100 Gm official acetic acid?

902. How much sodium hydroxide will replace 100 Gm of KOH in precipitating mercuric oxide from HgCl_2 ?

903. How much ferric oxide will be obtained by igniting 100 parts ferrous oxalate?

904. How much CaCl_2 can be prepared from 100 parts CaCO_3 , and how much official hydrochloric acid will be required?

905. How much precipitated ferric pyrophosphate can be made from 100 parts of the official solution of normal ferric sulphate?

906. How much N_2O , by weight and by volume, can be obtained by the decomposition of 100 Gm of H_4NONO_2 ?

907. How much Sb_2O_3 and cream of tartar are required to make one pound tartar emetic?

908. What quantities of $\text{Pb}(\text{NO}_3)_2$ and KI are required to make 1,000 parts PbI?

909. How much P and $\text{Ca}(\text{OH})_2$ will be required for making 1,000 Gm $\text{Ca}(\text{PH}_2\text{O}_2)_2$?

910. How much acetic acid containing 36 per cent. $\text{HC}_2\text{H}_3\text{O}_2$ is required to convert into zinc acetate: **a)** 100 parts zinc carbonate; **b)** 100 parts zinc oxide?

911. How much HNO_3 can be made from 100 lb sodium nitrate, and how much H_2SO_4 will be required?

912. How much official solution of ferric chloride is required to make the same quantity of ferric hydroxide as would be obtained from 1 kilogram of the official solution of ferric sulphate?

913. How much Epsom salt is necessary to produce 100 lb of the official magnesium carbonate?

914. What percentage of SO_2 can be obtained from: **a)** potassium sulphite; **b)** sodium sulphite; **c)** calcium sulphite; and **d)** magnesium sulphite?

915. How much crystallized sodium pyrophosphate may be made from 100 lb of bone ash?

916. How much lead acetate can be made from 1,000 parts PbO , and how much official acetic acid would it require?

917. How much CO_2 , by weight and by measure, can be

made from: **a)** 100 lb sodium bi-carbonate; **b)** 100 lb chalk? And how much sulphuric acid of 1.830 sp. w. would be required for each?

918. How much potassium acetate can be made from 1 pound official acetic acid, and how much potassium acid carbonate would be required?

919. How much of the official stronger ammonia water is required to convert 1 lb of citric acid into di-ammonium-hydrogen citrate?

920. What amount of antimonious oxide can be made by roasting 10 lb of black sulphide of antimony?

921. How much calcium oxide is required to make 1,000 grains of calcium hydroxide?

922. What materials are required to make 100 lbs red oxide of mercury from Hg and HNO_3 ?

923. What quantity of cream of tartar is required to make 100 lbs Rochelle salt?

924. How much hydrochloric acid of 32 per cent. strength, and how much soda ash should be obtained from 2,000 lbs of salt, approximately, and what other materials are necessary?

925. How much chalk is it necessary to decompose in order to produce the quantity of CO_2 required to convert 100 lbs of potash into KHCO_3 , and how much 90 per cent. sulphuric acid will be consumed?

926. Calculate the quantities of lime and potassium chloride required to make 100 lbs of potassium chlorate, by Liebig's process, and the quantities of black oxide of manganese, salt and 92 per cent. sulphuric acid required to produce the chlorine for the purpose.

927. What quantity of anhydrous normal ferric citrate will be obtained from 100 Gm citric acid, and how much iron will be contained in that quantity of ferric citrate?

928. What is the quantity of trihydrated quinine required to make 100 ounces of official citrate of iron and quinine, and how much of the official sulphate of quinine is required to produce that amount of the trihydrated alkaloid?

929. How much KBr is required to make 10 lb of 34 per cent. hydrobromic acid?

930. If water absorbs $2\frac{1}{2}$ times its volume of H_2S , how much

ferrous sulphide and how much 92 per cent. sulphuric acid will be consumed in generating a sufficient quantity of the gas to saturate two liters of water?

931. What will be the percentage of hydrogen chloride present in a 63 per cent. nitric acid made from potassium nitrate containing 10 per cent. of sodium chloride?

932. How much potassium iodate will be formed when potassium iodide is prepared by dissolving 10 lbs of iodine in a sufficient quantity of potassium hydroxide solution? How much potassium hydroxide will be required, and how much potassium iodide will be obtained?

CHAPTER XV.

PROBLEMS IN VOLUMETRIC ANALYSIS.

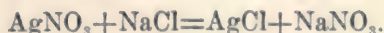
152. The **solute** of a water solution is the substance held in solution in the water.

153. The **mole** or gram-molecular-weight of any substance is the weight in grams indicated by the number expressing its molecular weight.

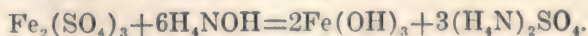
154. When the factors of chemical reactions are employed in the form of solutions it is generally practicable to simplify the proportions and computations by making the solutions of such strength that given weights or volumes bear simple relations to the atomic or molecular weights of the solutes.

Thus, as the molecular weight of dimeta-nitric acid is 62.57, its mole is 62.57 grams; and a mole of sodium hydroxide is 39.76 grams, its molecular weight being 39.76. A solution containing 63 per cent. of HNO_3 and a solution containing 40 per cent. of NaOH accordingly neutralize each other evenly, weight for weight.

One kilogram of a solution containing 168.7 Gm of silver nitrate will separate all the chlorine in the form of silver chloride from one kilogram of a solution containing 58 Gm of sodium chloride, because the molecular weights of AgNO_3 and NaCl are, respectively, 168.7 and 58, and one molecule of each is required for complete reaction as shown by the equation



One kilogram of a solution containing 397 Gm of $\text{Fe}_2(\text{SO}_4)_3$ will require six kilograms of a solution containing 34.8 Gm of H_4NOH in each kilogram, because the molecular weight of ferric sulphate is 397 and that of ammonium hydroxide is 34.8, and the reaction requires one molecule of the iron compound and six molecules of the H_4NOH ;



It is evident that instead of one molecule of $\text{Fe}_2(\text{SO}_4)_3$ and six molecules of H_4NOH we may use one-sixth of the gram-molecular-weight of the iron salt and one gram-molecular-weight of ammonium hydroxide.

155. The chemical equivalents of acids, bases and salts are their respective molecular weights divided by the total valence units of their negative ions.

Thus, as the anion OH is monovalent and the anion SO_4 is divalent, it follows that the "equivalent" of H_4NOH is its molecular weight and that of $\text{Fe}_2(\text{SO}_4)_3$ must be its molecular weight divided by 6 as the divalent SO_4 is contained three times in the molecule of ferric sulphate.

The equivalents or mutually exchangeable combining quantities of elements are their respective atomic weights divided by their valences in the compounds they form.

Thus the equivalent of hydrogen is 1; that of oxygen is 8 (16 divided by 2); that of aluminum is 9 (27 divided by 3); that of ferrous iron is 28 (56 divided by 2); that of ferric iron is 18.67 (56 divided by 3); that of mercurous mercury is 200; that of mercuric mercury, 100; that of chlorine in all chlorides is 35.5.

It will be seen from the foregoing that the equivalent of each element in any binary compound is its atomic weight divided by the number of atoms of the other element, since the equivalent of any element is its atomic weight divided by its valence.

It will be seen further that the equivalent of any compound constituting one of the factors of a double decomposition is its molecular weight divided by the number of molecules required of the other factor for complete metathesis. The equation—

$2\text{Al}(\text{OH})_3 + 3\text{H}_2\text{SO}_4 = \text{Al}_2(\text{SO}_4)_3 + 6\text{H}_2\text{O}$ gives us 25.85 and 48.67 as the respective "equivalents" of the factors for the molecular weight of the aluminum hydroxide is 77.54, which must be divided by the number of molecules of H_2SO_4 , and the molecular weight of the sulphuric acid which is 97.35 must be divided by the number of molecules of $\text{Al}(\text{OH})_3$ required according to the equation.

A **gram-equivalent** of any substance is the weight in grams indicated by its **equivalent**.

156. Volumetric solutions are solutions of which given volumes contain definite quantities by weight of the reagents, their respective strengths bearing simple relations to the atomic or molecular weights.

A **molar solution** is one of which one liter contains one mole of the solute.

A **normal solution** is one of which one liter contains one gram-equivalent of the solute.

A **normal volumetric test solution** of hydrogen chloride is a solution containing 36.18 Gm of HCl in each liter; HCl is the solute of that solution; the chemical equivalent of HCl is 36.18; its gram-equivalent is 36.18 Gm; its mole or gram-molecular-weight is 36.18 Gm and this solution is a molar solution as well as a normal solution.

A normal volumetric test-solution of sulphuric acid is a solution containing 48.67 Gm of absolute H_2SO_4 in each liter; the mole or gram-molecular-weight of H_2SO_4 is 97.35 Gm because its molecular weight is 97.35; its equivalent is one-half of 97.35, or 48.67 because the equivalent of any acid, base, or salt is its molecular weight divided by the total valence units of its negative ion in one molecule, and the valence of SO_4 is 2.

157. A "normal solution" of an oxidizing agent is one which in each liter contains a mole of the compound of the oxidizing element divided by the total units of algebraic combining value furnished by each molecule of that compound; or, if the oxidizing agent be an uncombined element, its normal solution contains in each liter the number of grams of that element expressed by its atomic weight divided by the number of units of algebraic combining value given up by it in oxidation.

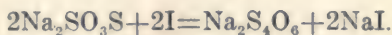
Thus a normal solution of potassium permanganate is one containing 31.396 Gm of KMnO_4 in each liter because the molecular weight of the compound is 156.98 and the manganese atom in it has the algebraic combining number 7 which by the reaction is reduced to 2 so that five units of combining value

are furnished by each molecule of the KMnO_4 , and one-fifth of 156.98 is 31.396.

A normal solution of $\text{K}_2\text{Cr}_2\text{O}_7$ is one containing 48.713 Gm of that salt in each liter because the molecular weight of potassium dichromate is 292.28 and the two chromium atoms in the molecule are reduced from a value of +6 each to a value of +3 each, and one-sixth of 292.28 is 48.713.

A normal solution of iodine contains 125.9 Gm of iodine in each liter because the atomic weight of I is 125.9 and when the solution is used as an oxidizing agent each atom of the I is reduced from a value of 0 to one of -1 thus furnishing one unit of oxidation.

A normal solution of the reducing agent sodium thiosulphate is one containing 246.46 Gm of that salt in each liter, because the molecular weight of $\text{Na}_2\text{SO}_3\text{S}$ added to five times the molecular weight of water (the composition of the reagent being $\text{Na}_2\text{SO}_3\text{S}+5\text{H}_2\text{O}$) makes the sum of 246.46. When used as a reducing agent it is converted into sodium tetra-thionate having the composition $\text{Na}_2\text{S}_4\text{O}_6$. In the $\text{Na}_2\text{SO}_3\text{S}$ the acidic sulphur atom has the combining value +6 and the other a value of -2; in the $\text{Na}_2\text{S}_4\text{O}_6$ there are two acidic sulphur atoms each having a value of +6, one sulphur atom having a value of -2 and another having a value of 0. The equation representing the reaction between $\text{Na}_2\text{SO}_3\text{S}$ and I is:



Evidently the four atoms of sulphur which in the two molecules of $\text{Na}_2\text{SO}_3\text{S}$ had a total combining value of +8 gained two units for in the $\text{Na}_2\text{S}_4\text{O}_6$ their total value is +10; the sulphur in **one** molecule of $\text{Na}_2\text{SO}_3\text{S}$, therefore, gained only 1 unit. Accordingly the normal solution of $\text{Na}_2\text{SO}_3\text{S}$ should contain in one liter one mole of the salt.

158. A normal solution reduced to one-tenth of the standard strength is called a deci-normal solution and one of one-hundredth of the normal strength is called a centi-normal solution. A solution of twice the normal strength is double-normal. Volumetric test-solutions of half-strength, and of

other strengths are also used. A double-normal solution is designated as $\frac{2N}{1}$; a normal solution as $\frac{N}{1}$; a half-normal as $\frac{N}{2}$; a quarter-normal as $\frac{N}{4}$; but solutions may be $\frac{N}{3}$, $\frac{N}{5}$, $\frac{N}{6}$, $\frac{N}{20}$, $\frac{N}{25}$, $\frac{N}{30}$, $\frac{N}{40}$, or other strengths according to convenience.

159. Volumetric estimations are based upon reactions of neutralization, precipitation, or oxidation, which proceed to completion so that either both factors, or at least one of them, is wholly consumed.

160. By the term **iodimetry** is meant the quantitative determination of certain reducing agents or oxidizable substances by means of free iodine which acts as an oxidizing agent, and the indirect determination of the amounts of certain reducible substances by the liberation of iodine from potassium iodide the quantity of free I being then found by means of a reducing agent like sodium thiosulphate.

161. The quantity employed of the sample tested may be any convenient quantity. It is, however, often most convenient to employ of the substance quantities bearing simple relations to the atomic or molecular weight of the element or compound the quantity of which is to be determined.

The per cent. of any element of which a given compound contains one atom is found by dividing one hundred times the atomic weight of that element by the molecular weight of the compound. Thus, the per cent. of metallic iron in crystallized ferrous sulphate, $\text{FeII}_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$, is found by multiplying 55.5 by 100 and dividing the product by 276; and when the molecular weight of any compound is multiplied by its per cent. of any given element one atom of which is contained in the molecule of that compound, the product must be one hundred times the atomic weight of that element.

In the iodimetric determinations applied to ferric compounds the combining value of each iron atom is changed from +3 to +2, and one iodine atom from the KI is liberated by each iron atom. The quantities of HCl and KI usually added are in excess of the theoretical proportions required, but as

the quantity of iodine liberated must be in exact proportion to the iron reduced the student will see that the only values which need be considered in the computations are the quantity of iron compound taken for the test and the quantity of volumetric solution of sodium thiosulphate. Each ml of $\frac{N}{10}$ solution of the thiosulphate required to convert the iodine into sodium iodide indicates the presence in the test sample of 0.00555 Gm of iron because the atomic weight of iron is 55.5.

162. The following reactions illustrate the employment of oxidizing agents and reducing agents in volumetric analyses.

1. $K_2Cr_2O_7 + 14HCl = 2KCl + 2CrCl_3 + 7H_2O + 6Cl_2^*$
2. $K_2Cr_2O_7 + 4H_2SO_4 + 3SO_2 = 2KCr(SO_4)_2 + 3H_2SO_4 + H_2O.$
3. $K_2Cr_2O_7 + 6FeSO_4 + 7H_2SO_4$
 $= 2KCr(SO_4)_2 + 3Fe_2(SO_4)_3 + 7H_2O.$
4. $K_2Cr_2O_7 + 6FeCl_2 + 6HCl + 4H_2SO_4$
 $= 2KCr(SO_4)_2 + 6FeCl_3 + 7H_2O.$
5. $5H_2O_2 + 2KMnO_4 + 3H_2SO_4$
 $= K_2SO_4 + 2MnSO_4 + 8H_2O + 10O.$
6. $5H_2SO_3 + 2KMnO_4 + 3H_2SO_4$
 $= K_2SO_4 + 2MnSO_4 + 5H_2SO_4 + 3H_2O.$
7. $5(H_2C_2O_4 + 2H_2O) + 2KMnO_4 + 3H_2SO_4$
 $= K_2SO_4 + 2MnSO_4 + 18H_2O + 10CO_2.$
8. $5HPH_2O_2 + 4KMnO_4 + 6H_2SO_4$
 $= 5H_3PO_4 + 2K_2SO_4 + 4MnSO_4 + 6H_2O.$
9. $10(FeH_2SO_5 + 6H_2O) + 2KMnO_4 + 8H_2SO_4$
 $= K_2SO_4 + 2MnSO_4 + 5Fe_2(SO_4)_3 + 78H_2O.$
10. $5FeCl_2 + KMnO_4 + 4H_2SO_4$
 $= Fe_2(SO_4)_3 + 3FeCl_3 + KCl + MnSO_4 + 4H_2O.$
11. $5FeCl_2 + KMnO_4 + 8HCl = 5FeCl_3 + KCl + MnCl_2 + 4H_2O.$
12. $SO_2 + 2I + 2H_2O = H_2SO_4 + 2HI.$
13. $NaHSO_3 + 2I + H_2O = NaHSO_4 + 2HI.$
14. $As_2O_3 + 8NaHCO_3 + 4I$
 $= 2Na_3HAsO_4 + 4NaI + 3H_2O + 8CO_2.$

*Heat is required to cause this reaction.

15. $\text{OSbKC}_4\text{H}_4\text{O}_6 + 2\text{I} + 4\text{NaHCO}_3$
 $= \text{NaSbO}_3 + 2\text{NaI} + \text{KNaC}_4\text{H}_4\text{O}_6 + 3\text{H}_2\text{O} + 4\text{CO}_2.$
16. $2\text{Na}_2\text{SO}_3\text{S} + 2\text{I} = \text{Na}_2\text{S}_4\text{O}_6 + 2\text{NaI}.$
17. $\text{FeCl}_3 + \text{KI} = \text{FeCl}_2 + \text{KCl} + \text{I}.$
18. $\text{Fe}_2(\text{SO}_4)_3 + 2\text{KI} = 2\text{FeSO}_4 + \text{K}_2\text{SO}_4 + 2\text{I}.$
19. $\text{Fe}(\text{NO}_3)_3 + \text{KI} = \text{Fe}(\text{NO}_3)_2 + \text{KNO}_3 + \text{I}.$
20. $\text{FeH}_4\text{N}(\text{SO}_4)_2 + \text{KI} = \text{FeSO}_4 + \text{KH}_4\text{NSO}_4 + \text{I}.$
21. $\text{Fe}_4\text{O}(\text{SO}_4)_5 + 2\text{HCl} + 4\text{KI}$
 $= 4\text{FeSO}_4 + \text{K}_2\text{SO}_4 + 2\text{KCl} + 4\text{I} + \text{H}_2\text{O}.$
22. $\text{Fe}(\text{C}_2\text{H}_3\text{O}_2)_3 + 3\text{HCl} + \text{KI} = \text{FeCl}_2 + \text{KCl} + 3\text{HC}_2\text{H}_3\text{O}_2 + \text{I}.$
23. $\text{FeC}_6\text{H}_5\text{O}_7 + 3\text{HCl} + \text{KI} = \text{FeCl}_2 + \text{KCl} + \text{H}_3\text{C}_6\text{H}_5\text{O}_7 + \text{I}.$
24. $\text{FeK}(\text{C}_4\text{H}_4\text{O}_6)_2 + 2\text{HCl} + \text{KI} = \text{FeCl}_2 + 2\text{KHC}_4\text{H}_4\text{O}_6 + \text{I}.$
25. $\text{FeH}_4\text{N}(\text{C}_4\text{H}_4\text{O}_6)_2 + 2\text{HCl} + \text{KI} = \text{FeCl}_2 + \text{H}_4\text{NKC}_4\text{H}_4\text{O}_6 + \text{I}.$
26. $\text{FePO}_4 + 3\text{HCl} + \text{KI} = \text{FeCl}_2 + \text{KCl} + \text{H}_3\text{PO}_4 + \text{I}.$
27. $\text{Fe}_4(\text{P}_2\text{O}_7)_3 + 12\text{HCl} + 4\text{KI} = 4\text{FeCl}_2 + 4\text{KCl} + 3\text{H}_4\text{P}_2\text{O}_7 + 4\text{I}.$

EXAMPLES.

933. How much KOH is contained in 1 ml of its normal solution?

934. How much $\frac{N}{1}$ V. S. of KOH is required to neutralize 5.86 Gm of a mixture of equal parts by weight of the official diluted hydrochloric and hydrobromic acids?

935. What per cent. of KOH is contained in a solution of which 21 Gm requires 75 ml of $\frac{N}{1}$ V. S. of H_2SO_4 ?

936. How much dry H_3N is represented by an ammonia solution which requires 24 ml of the $\frac{N}{1}$ V. S. of H_2SO_4 ?

937. How much normal solution of H_2SO_4 will be neutralized by 1 Gm of NaHCO_3 ?

938. How much potassium bicarbonate will neutralize 25 ml of $\frac{N}{1}$ solution of H_2SO_4 ?

939. What per cent. of H_3N is contained in an alcoholic solution of ammonia of which 3.4 Gm neutralizes 50 ml of $\frac{N}{2}$ solution of H_2SO_4 ?

940. What per cent. of $\text{HOPbC}_2\text{H}_3\text{O}_2$ is contained in a solution of which 14 Gm requires 25 ml of $\frac{N}{1}$ V. S. of H_2SO_4 for complete precipitation?

941. If 1.62 Gm of $\text{K}_3\text{C}_6\text{H}_5\text{O}_7 + \text{H}_2\text{O}$ be thoroughly ignited at red heat and the residue dissolved in water how much $\frac{N}{1}$ V. S. of H_2SO_4 will be required to neutralize that solution?

942. How much Li_2CO_3 will be obtained by complete ignition of 5 Gm of lithium salicylate ($\text{LiC}_7\text{H}_5\text{O}_3$)? And how much normal solution of sulphuric acid is required to neutralize that carbonate?

943. How much $\text{H}_4\text{NHCO}_3 \cdot \text{H}_4\text{NCO}_2 \cdot \text{NH}_2$ is contained in a solution of that substance when 15.7 Gm of that solution neutralizes 100 ml of $\frac{N}{10}$ V. S. of $\text{H}_2\text{C}_2\text{O}_4 + 2\text{H}_2\text{O}$?

944. How much $\text{Na}_2\text{CO}_3 + \text{H}_2\text{O}$ is required to neutralize 100 ml of $\frac{N}{10}$ solution of oxalic acid?

945. What per cent. of NaOH is contained in a solution of which 10 Gm neutralizes 25 ml of $\frac{N}{1}$ solution of $\text{H}_2\text{C}_2\text{O}_4 + 2\text{H}_2\text{O}$?

946. What quantity of $\frac{N}{10}$ solution of $\text{H}_2\text{C}_2\text{O}_4 + 2\text{H}_2\text{O}$ is exchangeable for 10 ml of $\frac{N}{10}$ solution of H_2SO_4 ?

947. What is the per cent. of $\text{Ca}(\text{OH})_2$ in lime water of which 30 Gm requires 18 ml of $\frac{N}{10}$ V. S. of $\text{H}_2\text{C}_2\text{O}_4 + 2\text{H}_2\text{O}$ for complete precipitation?

948. How much K_2CO_3 is contained in a potassium iodide of which 10 Gm in solution requires 1 ml of $\frac{N}{10}$ V. S. of $\text{H}_2\text{C}_2\text{O}_4 + 2\text{H}_2\text{O}$ for neutralization?

949. How much $\text{H}_3\text{C}_6\text{H}_5\text{O}_7 + \text{H}_2\text{O}$ neutralizes 30 ml of $\frac{N}{1}$ solution of KOH ?

950. What per cent. of absolute $\text{HC}_2\text{H}_3\text{O}_2$ is contained in

a solution of which 1.5 Gm neutralizes 25 ml of normal solution of KOH?

951. How much water must be added to an acetic acid of which 5 Gm neutralizes 50 ml of normal solution of NaOH in order to reduce its strength to 36%?

952. If a solution of cream of tartar requires 10 ml of normal solution of KOH for complete neutralization how much potassium bitartrate is contained in it?

953. How much normal solution of KOH neutralizes 5 Gm of an 80% solution of $\text{HC}_3\text{H}_5\text{O}_3$?

954. What is the strength of a sulphuric acid of which 9.8 Gm neutralizes 10 ml of $\frac{N}{1}$ solution of NaOH?

955. The molecular weight of H_2SO_4 being 98, how much of the acid is contained in one liter of its normal solution?

956. What per cent. of silver is contained in a solution of silver nitrate which requires 20 ml of $\frac{N}{10}$ solution of NaCl for complete precipitation? And why?

957. How much AgNO_3 is required to make one-half liter of decinormal solution? And why?

958. What is the % strength of a hydrogen cyanide solution of which 2 Gm requires 22.22 ml of $\frac{N}{10}$ solution of silver nitrate for complete precipitation? And why?

959. How much $\frac{N}{10}$ solution of AgNO_3 is required for complete precipitation of 3 Gm of a hydrocyanic acid of 2% strength? And why?

960. How much LiBr is contained in 3 Gm of a solution requiring 34 ml of $\frac{N}{10}$ solution of AgNO_3 for complete precipitation?

961. How much NaBr is contained in a solution the whole of which requires 10 ml of $\frac{N}{10}$ solution of AgNO_3 for complete precipitation?

962. How much $\frac{N}{10}$ solution of AgNO_3 is required for complete precipitation of a solution containing 1 Gm of KI?

963. How much pure KI is contained in a solution of which 2 Gm is completely precipitated by 12 ml of $\frac{N}{10}$ solution of AgNO_3 ?

964. How much pure KBr is contained in a solution 2 Gm of which requires 12 ml $\frac{N}{10}$ solution of silver nitrate for precipitation?

965. How much pure KCl in 2 Gm of a solution requiring 12 ml decinormal silver nitrate solution for precipitation?

966. How much decinormal silver nitrate solution is required to completely precipitate a solution containing 1 Gm of KI? One Gram of KBr? One Gm of KCl?

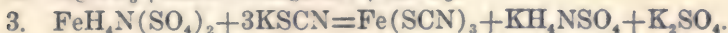
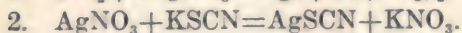
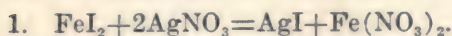
967. How much decinormal AgNO_3 V. S. is required to completely precipitate a solution of 1 Gm of KI sold as pure but which contains 10% of KBr?

968. How much $\frac{N}{10}$ solution of AgNO_3 is required to completely precipitate 5 Gm of a solution containing 20% of a mixture consisting of 50% KI, 20% KBr, and 30% KCl?

969. How much potassium thiocyanate is contained in 1 ml of its decinormal solution?

970. If 3 Gm of syrup of ferrous iodide be mixed with 20 ml of water, 21 ml of decinormal solution of silver nitrate, 10 ml of dilute nitric acid and 10 ml of T. S. of iron alum (enough to act as an indicator), and if this mixture requires 2 ml of $\frac{N}{10}$ solution of potassium thiocyanate to produce a reddish brown color which is not discharged on shaking: How much FeI_2 is contained in the syrup?

The reactions are:



971. How much iodine is contained in 1 ml of its decinormal solution?

972. The molecule of iodine at any temperature below 600° is diatomic. Is it true (as sometimes stated) that a

normal solution of iodine must contain 126.5 Gm of iodine in each liter because "the molecular weight divided by the valence" requires it? If not, what determines the strength of a V. S. of iodine?

973. The molecular formula for sodium thiosulphate is $\text{Na}_2\text{SO}_3\text{S}$ and the crystallized salt is a pentahydrate. How much of the salt must be contained in one liter of its decinormal solution? Is the strength of that solution fixed according to the "equivalent" and the number of atoms of the sodium in it? What determines its strength?

974. Designating the molecular weight of a given compound as a, the atomic weight of a given element in that compound as b, the number of atoms of the element contained in one molecule of the compound as c, the per cent. which the compound contains of the element as d, what is the answer to the following problem?

$$\frac{b \times c}{a \times d}$$

975. The molecular weight of a certain iron compound is 270; the proportion of iron in that compound is 20.74 per cent.; and the atomic weight of iron is 56. How many iron atoms does that compound contain? And why?

976. What is the product obtained by multiplying the molecular weight of any iron compound by the per cent. of iron in it, when that iron compound contains 1 atom of iron in each molecule? When it contains 2 atoms of iron in each molecule? When it contains 3 atoms of Fe in each molecule? What relation does the atomic weight of Fe bear to the answers?

977. Assuming that a certain specimen of ferric chloride contains 20% of iron, the composition being—

$$\begin{array}{r} \text{FeCl}_3 = 162 \\ 5\text{H}_2\text{O} = 108 \\ \text{Moisture} = 10 \\ \hline \text{Total} \quad 280 \end{array}$$

and the reciprocal of 280 being 0.357143, what is the quotient obtained by dividing 20 by that reciprocal?

978. What advantage is derived from using 0.56 Gm instead of any other quantity of ferric citrate to perform the iodimetric method of determining the per cent. of Fe in it?

979. How many ml of $\frac{N}{10}$ solution of sodium thiosulphate will be required to discharge the color in the iodimetric test of a ferric compound containing 16% of Fe? And why?

980. How much $\frac{N}{10}$ solution of sodium thiosulphate is required to decolorize 10 ml of $\frac{N}{10}$ solution of iodine and how much iron is indicated by 10 ml of $\frac{N}{10}$ solution of the thiosulphate in the iodimetric test?

981. How much $\frac{N}{10}$ solution of iodine must be added to a solution containing 0.248 Gm of sodium thiosulphate to produce a permanent iodine reaction on starch mucilage?

982. How much H_2SO_3 is contained in a solution 1 Gm of which requires 20 ml of $\frac{N}{10}$ solution of iodine to impart the blue color to added starch mucilage? And why?

983. How much $\frac{N}{10}$ solution of iodine is decolorized by a solution prepared from 0.2 Gm of As_2O_3 and 2 Gm of $NaHCO_3$? And why?

984. What per cent. of H_2AsHO_3 is contained in a solution 25 Gm of which (after having been boiled for a few minutes with 2 Gm of $NaHCO_3$) decolorizes 50 ml of $\frac{N}{10}$ solution of iodine? And why?

985. How much $Na_2SO_3 + 7H_2O$ will be required to decolorize 25 ml of $\frac{N}{10}$ iodine solution? And why?

986. If a solution be made of 0.3235 Gm of dry $OSbKC_4H_4O_6$, 10 Gm of water, and 20 ml of a cold saturated solution of $NaHCO_3$, and a few drops of T. S. of starch be added, how much $\frac{N}{10}$ solution of iodine will be required to produce a permanent blue color in the mixture? And why?

987. How much $\text{Na}_2\text{SO}_3 \cdot 5\text{H}_2\text{O}$ is contained in one liter of its decinormal solution? And why?

988. What per cent. of iodine is contained in a solution of which 12.65 Gm requires 30 ml of $\frac{N}{10}$ solution of sodium thiosulphate? And why?

989. If 2 Gm of KI and 25 Gm of water be added to 6.3 ml of an alcoholic solution of iodine, together with a little T. S. of starch, and this mixture requires 35 ml of $\frac{N}{10}$ solution of sodium thiosulphate to discharge the blue color, what per cent. of iodine is indicated? Why is the KI added?

990. A sample of chlorine water is to be tested for its chlorine strength. If 71 Gm of this solution be added to a solution made of 4 Gm of KI and 40 Gm of water the mixture becomes deep-red. Why? What is the object of adding the KI? If 28.75 Gm of this mixture requires 25 ml of $\frac{N}{10}$ sodium thiosulphate solution for complete decoloration, what per cent. of Cl did the sample contain? And how do you explain your conclusion? Why was 71 Gm of the chlorine water taken for the test? Could the test be made with a smaller quantity if necessary? And how? And why use 28.75 of the mixture of chlorine water and KI solution?

991. If 0.30 Gm of chlorinated lime be triturated with 50 Gm of water, the solution and washings transferred to a flask, 0.75 Gm of KI added, and finally 5 Gm of diluted hydrochloric acid, and if this mixture requires 30 ml of $\frac{N}{10}$ sodium thiosulphate solution for complete decoloration, what is the per cent. of chlorine in the chlorinated lime? Why? And why is the hydrogen chloride added?

992. The molecular weight of $\text{FeH}_4\text{N}(\text{SO}_4)_2$ is 266. What per cent. of iron is contained in its dodekahydrate?

993. If a solution of ferric sulphate contains 28.7 per cent. of $\text{Fe}_2(\text{SO}_4)_3$ what per cent. of iron does it contain? And how is that per cent. of iron shown by the iodimetric method?

994. If you divide 5600 by the molecular weight of a ferric

compound, what proportion of the quotient represents the per cent. of iron in it?

995. A solution of ferric nitrate ($\text{Fe}(\text{NO}_3)_3=241.5$) contains 1.4 per cent. of iron. How many Gm of that solution must be equal to 241.5 Gm of $\text{Fe}(\text{NO}_3)_3$? What is the quotient obtained by dividing 5600 by 1.4? What is the per cent. of $\text{Fe}(\text{NO}_3)_3$ in the solution? What is the quotient found by dividing the molecular weight of the $\text{Fe}(\text{NO}_3)_3$ by 1.4?

996. If 28 Gm of crystalline ferric chloride dissolved in water be examined iodimetrically to find the amount of iron in it how many ml of $\frac{N}{10}$ solution of sodium thiosulphate must be required if the sample was pure $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$?

997. If 2.8 Gm of a solution of ferric chloride be subjected to iodimetric assay and 26 ml of $\frac{N}{10}$ solution of sodium thiosulphate is found to be required, what per cent. of FeCl_3 is contained in the solution tested?

What per cent. of $\text{FeCl}_3 + 6\text{H}_2\text{O}$ does it contain?

And what per cent. of iron?

998. I dissolve 1 Gm of ferric citrate in water, add HCl and KI, digest for half an hour, cool, add a few drops of starch mucilage, and then add $\frac{N}{10}$ sodium thiosulphate. How much of this V. S. will be required to discharge the blue color if the ferric citrate contains 16 per cent. of iron?

999. If 1.12 Gm of the "soluble ferric pyrophosphate" be tested by iodimetry how much sodium thiosulphate $\frac{N}{10}$ will be required if the preparation contains 10 per cent. of iron?

1000. If 2.24 Gm of solution of ferric acetate be tested by iodimetry to determine the per cent. of iron in it, and if then 20 ml of $\frac{N}{10}$ sodium thiosulphate be the quantity required to consume the free iodine, what per cent. of Fe is indicated?

1001. If 2.24 Gm of solution of ferric citrate requires 30 ml of $\frac{N}{10}$ sodium thiosulphate for the iodimetric test, how many Gm of iron does 100 Gm of that solution contain?

1002. If 4 Gm of solution of ferric nitrate liberates an amount of iodine consuming 10 ml of decinormal sodium thiosulphate solution, what per cent. of the nitrate was contained in the test sample?

1003. What quantity of $K_2Cr_2O_7$ is contained in 1 ml of its $\frac{N}{10}$ solution? Why is the solution made of that strength?

1004. How much $\frac{N}{10}$ potassium dichromate is required to convert 1.39 Gm of $FeH_2SO_5 + 6H_2O$ into $Fe_2(SO_4)_3$?

1005. How much $KMnO_4$ is contained in 200 ml of its decinormal solution? And why is it made of that strength?

1006. I have a solution containing an unknown quantity of oxalic acid; 2 Gm of this solution acidulated with H_2SO_4 decolorizes 10 ml of $\frac{N}{10}$ $KMnO_4$. What per cent. of $H_2C_2O_4$ does the sample contain? And what per cent. of $H_2C_2O_4 + 2H_2O$?

1007. If 5 ml of solution of hydrogen dioxide (properly diluted and acidulated with sulphuric acid) decolorizes 30 ml of $\frac{N}{10}$ permanganate of potassium, what per cent. of H_2O_2 does the sample contain?

1008. One Gm of diluted HPH_2O_2 is mixed with 14 ml of sulphuric acid and 70 ml of $\frac{N}{10}$ potassium permanganate and the mixture boiled for fifteen minutes. It then requires 10 ml of $\frac{N}{10}$ oxalic acid to discharge the red color. What per cent. of hypophosphorous acid does the sample contain?

The reactions are:

1. $5HPH_2O_2 + 6H_2O + 4KMnO_4$
 $= 5H_3PO_4 + 2K_2SO_4 + 4MnSO_4 + 6H_2O.$
2. $2KMnO_4 + 3H_2SO_4 + 5(H_2C_2O_4 + 2H_2O)$
 $= K_2SO_4 + 2MnSO_4 + 18H_2O + 10CO_2.$

What is the rationale of the method?

1009. I have a solution of ferrous sulphate of unknown strength. I find that 10 Gm of it, acidulated with H_2SO_4 , requires 30 ml of $\frac{N}{10}$ potassium permanganate to produce a permanent pink color. What per cent. of FeH_2SO_5 does the solution contain?

What per cent. of crystallized ferrous sulphate does that correspond to?

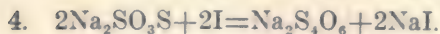
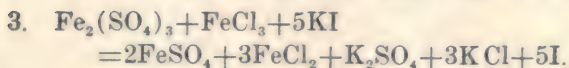
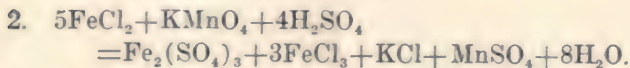
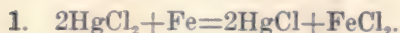
What per cent. of iron does it correspond to?

1010. I put 1 Gm of "reduced iron" in a bottle with 100 ml of a 5 per cent. solution of HgCl_2 , digest over a water-bath for an hour, shaking often, and then let cool; I then add 200 ml of water, and filter the liquid. I mix 10 ml of the filtrate with an equal volume of diluted sulphuric acid and then add enough $\frac{N}{10}$ potassium permanganate to produce a permanent pink color, and find that 9 ml of the V. S. is required to effect that result.

What is the per cent. of pure iron in the sample tested?

I now add a few drops of alcohol to decolorize the liquid and then 1 Gm of KI after which I heat the mixture at 40° for half an hour; then let cool and add some drops of starch mucilage. How much $\frac{N}{10}$ sodium thiosulphate will be required to discharge the blue color?

The reactions are:



1011. How many grams of iodine in a liter of the tincture, if 5 ml of it requires 49.5 ml of $\frac{N}{20}$ sodium thiosulphate to decolorize the iodine?

1012. Twenty-five ml of solution of potassium arsenite having a sp. gr. of 1.16 is diluted with 75 ml of water and 25 ml of this is titrated with $\frac{N}{20}$ iodine, after the addition of 0.5 gram of sodium bicarbonate. If 24.5 ml of the iodine solution is required to produce a permanent yellow tint, what per cent. of As_2O_3 is contained in the original solution?

1013. What weight of sodium chloride must be taken for titration, in order to have each ml of an $\frac{N}{10}$ silver nitrate V. S. indicated 0.5% of the pure salt?

1014. Syrup of ferrous iodide weighing 8 Gm is diluted with water to make 100 ml of solution and to 25 ml of this solution 20 ml of $\frac{N}{20}$ silver nitrate V. S. is added. If 12 ml of potassium thiocyanate V. S. is required to precipitate the excess of silver present, what per cent. of FeI_2 is contained in the syrup?

1015. How much ferric citrate must be taken in making the determination of the amount of metallic iron in the compound, if it is desired to have each ml of an $\frac{N}{20}$ sodium thiosulphate V. S. indicate one per cent. of metallic iron?

1016. What quantity of crystallized sodium carbonate is represented by a partly effloresced "sal sodæ" of which 4 Gm exactly neutralizes 5.5 Gm of cream of tartar known to be 99 per cent pure?

1017. What is the proportion of silver nitrate in a mixture of the nitrates of silver and potassium when 1 Gm of the mixture dissolved in water requires 20 ml of $\frac{N}{10}$ solution of NaCl for complete precipitation?

1018. What is the per cent. of "available chlorine" in a solution of chlorinated soda of which 5 Gm, mixed with a solution of 1.50 Gm of KI in 100 ml of water and 10 Gm "Hydrochloric acid" together with a sufficiency of starch mucilage, requires 40 ml of $\frac{N}{10}$ sodium thiosulphate solution for the discharge of the blue tint?

1019. If 0.50 Gm of dry KBr dissolved in 10 ml of water, with two drops of potassium chromate T. S. added, requires 30 ml of $\frac{N}{10}$ silver nitrate solution to produce a permanent red color of silver chromate, what per cent of KBr is contained in the sample?

1020. What is the proportion of $\text{FeH}_2\text{SO}_5 + 6\text{H}_2\text{O}$ is contained in a sample of green vitriol of which 4.16 Gm dissolved in water and acidulated with H_2SO_4 requires 49.50 ml of $\frac{N}{10}$ potassium dichromate solution to prevent further reaction for ferrous salt with potassium ferricyanide T. S.?

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